Volume 11 DECEMBER, 1941 Number 3

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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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NOTICE

Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 11, NO. 3, PP. 105–123, PLATES 1–4, FIGS. 1–5, DECEMBER, 1941

THE NATURE AND ORIGIN OF LAYERS OF FINE-TEXTURED MATERIAL IN SAND DUNES

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School of Forestry, Yale University

ABSTRACT

Buried soils in sand dunes on Cape Cod, Massachusetts, and near Glen Haven, Michigan, contain layers of fine-textured material. Field relations of the strata demonstrate that the material was wind-laid. The size, shape, and specific gravity of the fine material indicate that it was transported in suspension by wind.

Occurrence of plant remains in all of the fine-textured layers, and the fact that fine material is accumulating in forest stands at the present time points to the important rôle that vegetation plays in the accumulation of wind-blown material, even in humid regions. Wind-blown material accumulates in areas supporting vegetation as a result of deposition due to decreased wind velocity and as a result of preservation of the deposits from wind and water erosion.

Buried layers of soil may be observed at numerous points in the extensive area of sand dunes northwest of Provincetown, Massachusetts, on Cape Cod. Examination of some of these buried soils revealed a number of interesting features. The upper parts of the buried soils appeared to be relatively fine-textured; to possess, in some cases, peculiar dark-colored laminations, and to contain notable amounts of charcoal and other plant remains. During July 1940, essentially similar features were noted in buried soils in sand dunes on Sleeping Bear Point, near Glen Haven, Leelanau County, Michigan.[1] The fact that plant remains occurred in every fine-textured layer suggested that vegetation might have been associated in some way with the accumulation of the fine material.

An investigation was undertaken with the object of determining the nature and origin of the layers of fine-textured material observed in the dunes earlier referred to. The results are reported in the following pages.

REVIEW OF LITERATURE

The occurrence of buried soil layers, variously referred to as "soil lines," "humus layers" and "old forest beds" in sand dunes has been observed in many parts of the world as is indicated in the writings of Boase (1822, p. 142), Knowles (1878, 1880), Tension-Woods (1883, p. 60), Cowles (1899, pp. 104, 110–111, 298), Gerhardt (1900, pp. 91–92, 144–148), Coffey and Praeger (1904, p. 194), Westgate (1904, p. 14), and Cobb (1910, p. 86). Gerhardt reported four superposed soil layers, representing former land surfaces, in a dune in East Prussia and Cobb mentioned that Thoulet found five such layers in sand dunes near Aracachon, in the Landes of France. In most cases the buried layers were dark colored and contained plant remains. Burial of soil layers results from the advance of a wandering dune into an area stabilized by vegetation. In no instance which has come to the writer's attention have mechanical analyses been made of the material in the buried soil layers of sand dunes.

Movement of dune sands is principally by traction and to some extent by saltation. That is, the sand grains either are rolled or are lifted and carried in short jumps. The finer particles, which fall within the suspension competency of the winds, may be carried for considerable distances and not be deposited until outside the dune area where they originated. Udden (1894) concluded that the " . . . average largest size of quartz particles

[1] The writer is indebted to Prof. S. G. Bergquist of the department of geology, Michigan State College, for information on this locality.

that can be sustained in the air by ordinary winds is about 0.1 mm. in diameter." Stebutt (1930, p. 53) stated that the size of particles which the wind is able to pick up, and cause to remain in suspension for some time, does not exceed a diameter of 0.25 mm.

Wind is known to effect a sorting of inorganic particles. This sorting relates to size, shape, and specific gravity. Other things being equal, particles of small size are moved more readily by wind than are particles of large size. In a given locality dune sands deposited during relatively short periods of time tend to be excellently sorted since they are composed of grains which have been repeatedly winnowed and practically all the particles within the suspension competency of the winds have been removed. The view has been expressed that if dune sands are separated into size classes and the percentage of each class determined, it will usually be found that the second largest percentage falls on the coarser side of the largest percentage. Twenhofel (1939, p. 232) has pointed out that " . . . there is thus a relatively sharp break in grain quantity at that dimension where suspension competency began." Since suspension competency varies with wind velocity and since wind velocity varies greatly with time and place, anything like rigorous uniformity of dune sand size is not to be expected. Udden (1898) expressed the view that most of the grains in drifting sands (dune sands) fall within the limits of 0.5 and 0.125 mm. in diameter. Atterberg (1905) stated that most of the sand grains in dune ridges (where the material was coarsest) were 0.6–0.2 mm. in diameter. Both Cressey (1928) and Carroll (1939) gave values identical with those of Udden (1898). Westgate (1904, p. 11) worked in the same areas on Cape Cod where the present writer carried on his investigations. Consequently it is of interest to note the mechanical composition of material collected eight inches below the surface of a dune and characterized by Westgate as fairly representing the bulk of the Cape sands:

Size class, mm.	*Percentage of material*
6.0 –2.0	00.0
2.0 –1.0	16.8
1.0 –0.5	77.0
0.5 –0.25	5.2
0.25–0.05	1.0

The results of size sorting by wind are evident not only in the uniformity of dune sands but also in the uniformity of particles in deposits of the finer material that was transported in suspension. Udden (1898) stated that ". . . it appears therefore that the finest wind sediments, which may be laid down in such quantity as to form appreciable deposits, consist in the main of particles ranging from coarse to fine dust,[2] and do not have any markedly laminated structure." The maximum percentage of material in a large number of samples of atmospheric dust was found to fall between the diameter limits of about 0.062 and 0.016 mm. Stebutt (1930, p. 55) remarked on the uniform size of loess particles, up to 90 per cent falling within the size limits of 0.05 to 0.01 mm. Smith and Fraser (1935) regarded loess particles as generally falling within the size limits of 0.062 and 0.031 mm.

The importance of wind action in shape-sorting of sand grains has been discussed by MacCarthy and Huddle (1938). They held that much of the superior roundness of eolian sands, as compared with sands of other types, is due to shape-sorting. Rounded grains move faster and further by traction than do angular grains. On the other hand angular grains are more readily supported in suspension than are rounded ones. Twenhofel (1939, p. 230) has pointed out that ". . . the deposits made by aeolian agencies are not always composed of rounded particles. The transportation may have been short." Small, initially angular particles suspended in the air may be carried long distances in a very short time and still retain their angularity. Angular grains are generally reported as characteristic of loess (Smith and Fraser, 1935).

[2] Coarse dust, 0.0625–0.03175 mm.; fine dust, 0.015875–0.007937 mm.

There can be little doubt that wind action sorts dune sands according to their specific gravity. Cowles (1899, p. 108) observed that, "With the quartz there are conspicuous grains of black sand, largely hornblende and magnetite. These black grains often accumulate in streaks, persistent for considerable depths and apparently sifted by the wind. . . ." Cressey (1928, p. 27) stated that minerals of high specific gravity are largely absent in deposits of wind blown material that has been moved a considerable distance. Barrett (1930) reported that the percentage of heavy minerals (specific gravity > 2.87) in dune sand decreased in going from the beach to the top of a dune. Smith and Fraser (1935) wrote as follows: "The density of the dark minerals is such as to exclude the likelihood of appreciable amounts being carried very far by wind action, hence a light color is characteristic of loess deposits."

The role which plants play in the accumulation and retention of wind-blown sand has been recognized and described by many writers (Tarr, 1890; Russell, 1903, p. 33; Hovey, 1907, p. 405; Beadnell, 1909, p. 78; Cressey, 1928, p. 44). Of more immediate interest in connection with the present investigation is the accumulation by vegetation of fine particles carried in suspension by winds. This service of vegetation, particularly in dry regions, has been recognized repeatedly (Prejevalsky, 1879, p. 57; Udden, 1894; Shimek, 1897, 1903, 1908a, 1908b; Keyes, 1898; Shaler, 1899; Hedin, 1904; Savage, 1905; Grund, 1906, p. 551; Huntington, 1907a, p. 359, 1907b, p. 135, 148; Free, 1911; Chilcott, 1937). The statement of Keyes concerning the role played by vegetation in the deposition of loessial material is noteworthy, "Silt dust blown up from the valley strikes the thick vegetation and is acted upon in the same way that it is in water when the current is checked. The particles come to rest around the roots and gradually build up the ground. Each year's vegetation is on a little higher level than the last." Accumulation of fine wind-blown particles in areas supporting vegetation is due to (1) deposition as a result of diminished wind velocity (2) preservation of the deposits against wind and water erosion.

FIELD INVESTIGATION

Most of the field work upon which this report is based was carried out in the area of sand dunes northwest of Provincetown, Massachusetts, on Cape Cod. In this extensive area are found a variety of conditions; shifting dune sands devoid of any cover of higher plants as well as stabilized dunes bearing forest stands 110 or more years old occur. Buried soil profiles containing plant remains furnish conclusive evidence that dune stabilization by vegetation has frequently been followed by dune advance (plate 1, fig. A).

The field investigation was carried out at a number of stations where buried profiles had been exposed by wind erosion and at several stations where the dunes are now stabilized by forest vegetation. Profiles were exposed at each station and composite samples representing each horizon or layer were collected for laboratory analysis. At stations I, J, K, and L the soil was sampled at one inch vertical intervals to a maximum depth of five inches. Brief descriptions of several selected stations follow. All stations were on Cape Cod unless otherwise noted. For convenience, the various layers of soil material are referred to as horizons.

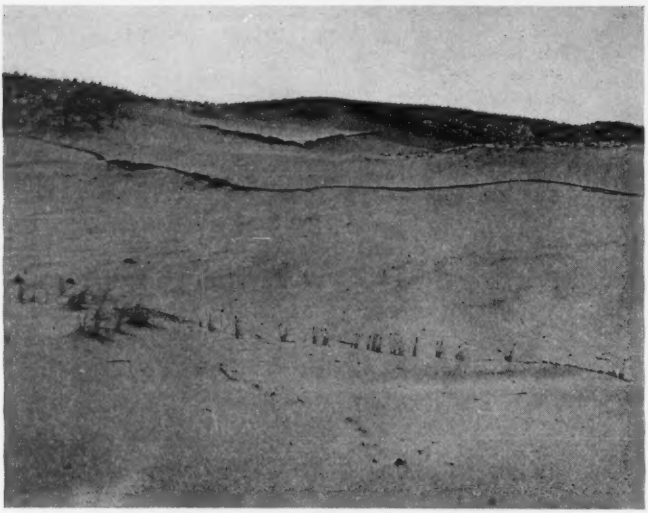
Station A.—Located in a blow-out in an area of shifting sands; practically no vegetation present.

Horizon 1.—Very light gray coarse sand[3]; 8–10 feet thick; one per cent of the material larger than 2 mm.

Horizon 2.—Light brownish gray fine sand; about 0.25 inch thick; few grains larger than 2 mm.; charcoal present.

Horizon 3.—Light gray loamy fine sand; 1.0–2.0 inches thick; irregularly laminated with organic matter; charcoal, bark fragments and wood abundant.

[3] Texture designations follow the nomenclature of Davis and Bennett (1927).



(A) Buried soil layers containing fine-textured material and plant remains in a sand dune on Cape Cod. The vertical distance between the layers is about 8 feet.

(B) A relatively mesic hardwood forest on a stabilized dune. Fine wind-blown material is accumulating under this stand at the present time. Station E, Cape Cod.

Horizon 4.—Dark gray coarse sand; about 0.25 inch thick; few grains larger than 2 mm., charcoal present.

Horizon 5.—Gray coarse sand; 2.0–3.5 inches thick; about 0.2 per cent of the material larger than 2 mm.; charcoal present.

Horizon 6.—Very light gray coarse sand; 5.0–6.0 inches thick; few grains larger than 2 mm.

Light grayish brown coarse sand at least 30.0 inches in depth occurs below horizon 6. Charcoal and wood fragments in the upper part of the buried soil body (horizons 2, 3, and 4) were identified as pitch pine (*Pinus rigida*).

Station B.—Located in a blow-out in an area of shifting sands; practically no vegetation present.

Horizon 1.—Very light gray coarse sand; 4–12 feet thick; 0.05 per cent of the material larger than 2 mm.

Horizon 2.—Light brownish gray sandy loam; trace to 0.2 inch thick; several fragments of wood present.

Horizon 3.—Gray loam; 1.0–1.5 inch thick; few grains larger than 2 mm.; irregularly laminated with organic matter; fragments of wood present.

Horizon 4.—Very light grayish brown coarse sandy loam; 0.25 inch thick.

Horizon 5.—Very light gray coarse sand; more than 2 feet thick; 0.4 per cent of the material larger than 2 mm.

Charcoal and wood fragments in the upper part of the buried soil body (horizons 2 and 3) were identified as pitch pine.

Station C.—Located on a stabilized dune ridge supporting a forest of pitch pine and black oak (*Quercus velutina*) about 70 years old. Shifting dunes occur about 250 feet to the west. The surface 2 feet of soil was not sampled.

Horizon 1.—Gray coarse sand; about 4 feet thick.

Horizon 2.—Dark gray fine sandy loam; 1.0–2.0 inches thick; some charcoal.

Horizon 3.—Blackish gray coarse sand; 2.0–3.0 inches thick; few grains larger than 2 mm.; charcoal abundant.

Horizon 4.—Light brownish gray coarse sand; 4.0–6.0 inches thick; few grains larger than 2 mm.; some charcoal.

Horizon 5.—Dark grayish brown coarse sand; 6.0 inches thick; few grains larger than 2 mm.

Horizon 6.—Light brown coarse sand; at least 18.0 inches thick; few grains larger than 2 mm.

In this profile, horizon 2 marks the uppermost part of the buried soil body.

Station D.—Located in a blow-out in a dune supporting a growth of beach plum (*Prunus maritima*), bayberry (*Myrica carolinensis*) and poison ivy (*Rhus toxicodendron*). About 1200 feet from the beach; no forest trees in the vicinity at present. The surface 2 feet of soil was not sampled.

Horizon 1.—Light gray coarse sand; 8–10 feet thick; 0.6 per cent of the material larger than 2 mm.

Horizon 2.—Gray sandy loam; 0.5–2.0 inches thick; laminated with organic matter; some charcoal.

Horizon 3.—Blackish gray coarse sand; 3.0–4.0 inches thick; very few grains larger than 2 mm.; charcoal very abundant.

Horizon 4.—Gray coarse sand; 10.0–12.0 inches thick; few grains larger than 2 mm.

Horizon 5.—Light gray coarse sand; at least 30.0 inches thick; 0.2 per cent of the material larger than 2 mm.

The uppermost part of the buried soil body in this profile is horizon 2. Charcoal in the upper part of the buried soil body (horizons 2 and 3) was identified as pitch pine.

Station E.—Located on the slope of a stabilized dune supporting a relatively mesophytic forest of beech (*Fagus grandifolia*), red maple (*Acer rubrum*), sour gum (*Nyssa sylvatica*), black oak, scarlet oak (*Quercus coccinea*) and service berry (*Amelanchier canadensis*). Dominant trees are 100–110 or more years old. Shifting dunes occur about 250 feet to the east. The vegetation at this station is shown in plate 1, figure B.

Horizon 1.—Grayish black fine sandy loam; 1.5–2.0 inches thick; very high content of organic matter.

Horizon 2.—Dark gray fine sand; 1.5–2.0 inches thick; charcoal present.

Horizon 3.—Light gray coarse sand; 3.5–5.0 inches thick; charcoal present.

Horizon 4.—Gray very fine sand; 1.5–2.0 inches thick; charcoal present; living tree roots are concentrated in this and the next lower horizon.

Horizon 5.—Dark gray coarse sand; 1.5–2.0 inches thick; charcoal present.

Horizon 6.—Light gray coarse sand; 4.0–5.0 inches thick; few grains larger than 2 mm.

Below horizon 6 is a layer of very light brownish gray coarse sand having a thickness of at least 18.0 inches. Horizon 4 forms the upper part of a buried soil body in this profile.

Station F.—This station was located in a blow-out in a dune area near Glen Haven, Michigan. Practically no vegetation was present on the shifting sands.

Horizon 1.—Very light brownish gray sand; 4 feet or more thick; few grains larger than 2 mm.; many shell fragments; calcium carbonate present.

Horizon 2.—Dark gray fine sand; 3.0–5.0 inches thick; calcium carbonate present.

Horizon 3.—Light brownish gray fine sand; at least 24.0 inches thick; calcium carbonate present.

Station G.—Located on a stabilized dune ridge in a pitch pine-black oak forest about 70 years old. Shifting dunes occur about 750 feet to the northeast.

Horizon 1.—Grayish black sandy loam; 1.0–2.0 inches thick; very high content of organic matter.

Horizon 2.—Light gray fine sand; 2.0–2.5 inches thick; irregularly laminated with organic matter; some charcoal.

Horizon 3.—Gray coarse sand; 2.0–3.0 inches thick; much charcoal; very few grains larger than 2 mm.

Horizon 4.—Very light gray coarse sand; 12.0 inches or more thick; very few grains larger than 2 mm.

Station H.—Located on a stabilized dune ridge in a black oak-pitch pine forest. No appreciable organic debris on the ground; about 700 feet from a shifting dune.

Horizon 1.—Dark gray loamy very fine sand; 1.0–1.5 inches thick; charcoal present.

Horizon 2.—Very dark gray coarse sand; 2.0–3.0 inches thick; charcoal present.

Horizon 3.—Light gray coarse sand; 4.0–6.0 inches thick.

Horizon 4.—Gray coarse sand; 12.0–14.0 inches thick.

Horizon 5.—Light brown coarse sand; more than 14.0 inches thick.

Station I.—Located adjacent to Station E.

0–1 inch depth.—Dark gray very fine sandy loam.

1–2 inch depth.—Dark gray coarse sand.

2–3 inch depth.—Gray coarse sand.

Station J.—Located adjacent to Station H.

0–1 inch depth.—Dark gray loamy fine sand.

1–2 inch depth.—Dark gray fine sandy loam.

2–3 inch depth.—Dark gray loamy coarse sand.

3–4 inch depth.—Dark gray coarse sand; much charcoal.

4–5 inch depth.—Gray coarse sand; some charcoal.

Station K.—Located adjacent to Station C.

0–1 inch depth.—Grayish black coarse sand.

1–2 inch depth.—Grayish black sandy loam.

2–3 inch depth.—Dark gray coarse sand; few grains larger than 2 mm.

3–4 inch depth.—Dark gray coarse sand; very few grains larger than 2 mm.

Station L.—Located adjacent to Station G.

0–1 inch depth.—Grayish black loamy coarse sand.

1–2 inch depth.—Dark gray loamy fine sand.
2–3 inch depth.—Gray sandy loam.
3–4 inch depth.—Dark gray coarse sand; much charcoal.
4–5 inch depth.—Dark gray coarse sand.

LABORATORY INVESTIGATION

The Bouyoucos (1936) method was employed in mechanical analyses of the soils. Results are shown in the form of histograms in figures 1, 2, and 3. The content of heavy minerals (specific gravity > 2.680) in the medium sand fraction (0.5–0.25 mm.) was determined by the method of Tamm (1934). Data concerning the percentage of heavy minerals are presented in figure 4. Moisture equivalent values were obtained for a number of profiles containing buried soil layers and appear in figure 5.

The soil separates from each horizon of a number of Cape Cod profiles were examined microscopically to observe the shapes of the particles. It was found that the particles in the 2.0–1.0 mm., 1.0–0.5 mm., and 0.5–0.25 mm. classes were well rounded. In general the surfaces of the grains had a frosted appearance; small fracture pits were common. The particles in the 0.25–0.10 mm. class were subangular, that is, the edges of the fracture surfaces had been abraded. Particles in the 0.10–0.05 mm. and 0.05–0.005 mm. classes were very definitely angular with fresh fracture surfaces and sharp edges. In the sands from the Michigan dune even particles in the 0.25–0.10 mm. size class were usually rounded. Material in the 0.10–0.05 mm. class was subangular and only material less than 0.05 mm. was definitely angular. The photomicrographs in plates 2 and 3 illustrate the shapes of the various size particles from horizons of two profiles.

The question arose as to the possibility of downward migration of fine particles (material <0.10 mm.) in dune sands under the influence of percolating water. To throw light on this question a glass tube about 48 inches long with an inside diameter of one inch was fixed in a vertical position. The lower end of this tube was caused to rest on a mat of organic debris obtained from a pitch pine forest. Sand obtained from an active dune was then placed in the vertical tube and water was allowed to drip on the surface of the sand. This was permitted to run for a period of two weeks at which time the apparatus was dismantled and the organic debris allowed to dry. A gray coating appeared on the surface of the organic matter and microscopic examination proved it to consist of fine, highly angular quartz particles which had been carried downward by the percolating water.

DISCUSSION

The fine-textured layers in buried soil profiles on Cape Cod vary in thickness from about 0.2 to over 2.0 inches; in the Michigan dune the layer varies from about 3.0 to 5.0 inches. As a rule the layers containing fine-textured material are sharply delimited from the layers of coarse sands above and below (plate 4, fig. A). However, it was noted in the field that layers underlying fine-textured material generally contained more particles smaller than 0.25 mm. than were found in normal dune sands. This field observation was corroborated by the mechanical analysis data. Probably there had been some downward movement of the fine particles into the underlying coarse sands.

Some of the layers of coarse sand contain small amounts of material more than 2.0 mm. in diameter. In only one layer (station A, horizon 1) did the amount reach as much as one per cent. Most of the layers of fine-textured material contain no particles larger than 2 mm.

In all cases the layers of fine-textured material contain plant remains in the form of charcoal, bits of wood and bark, or amorphous organic matter. In several instances the remains could be identified[4] as representing species at present common in the locality. Peculiar dark colored

[4] The writer is indebted to Prof. R. W. Hess of the School of Forestry, Yale University, for making the identifications.

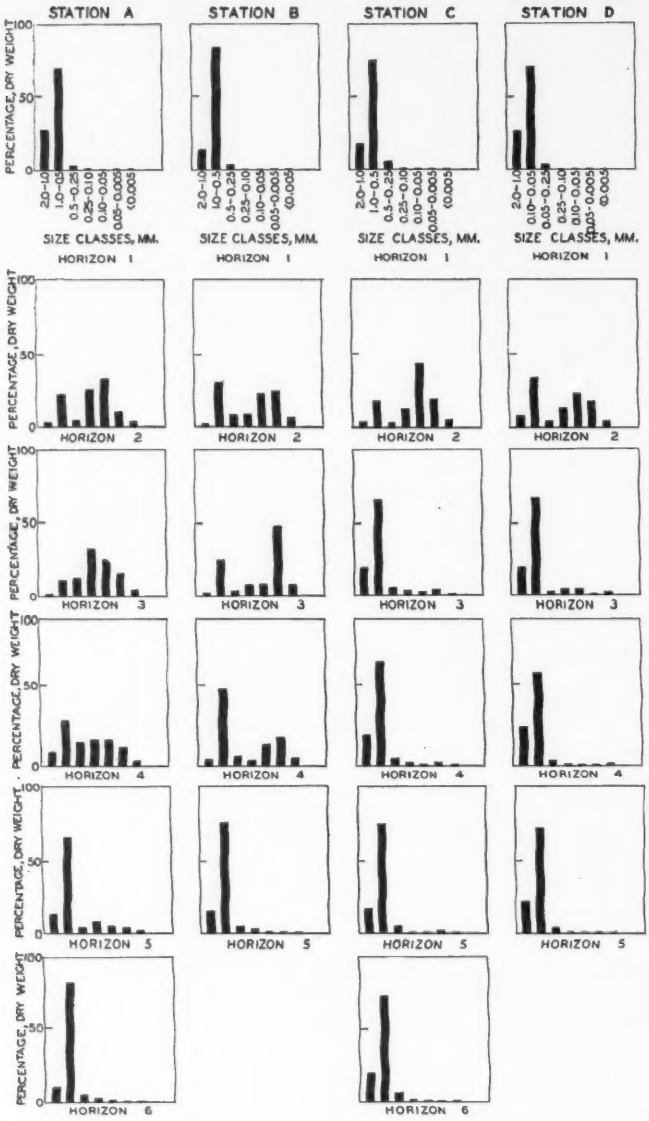


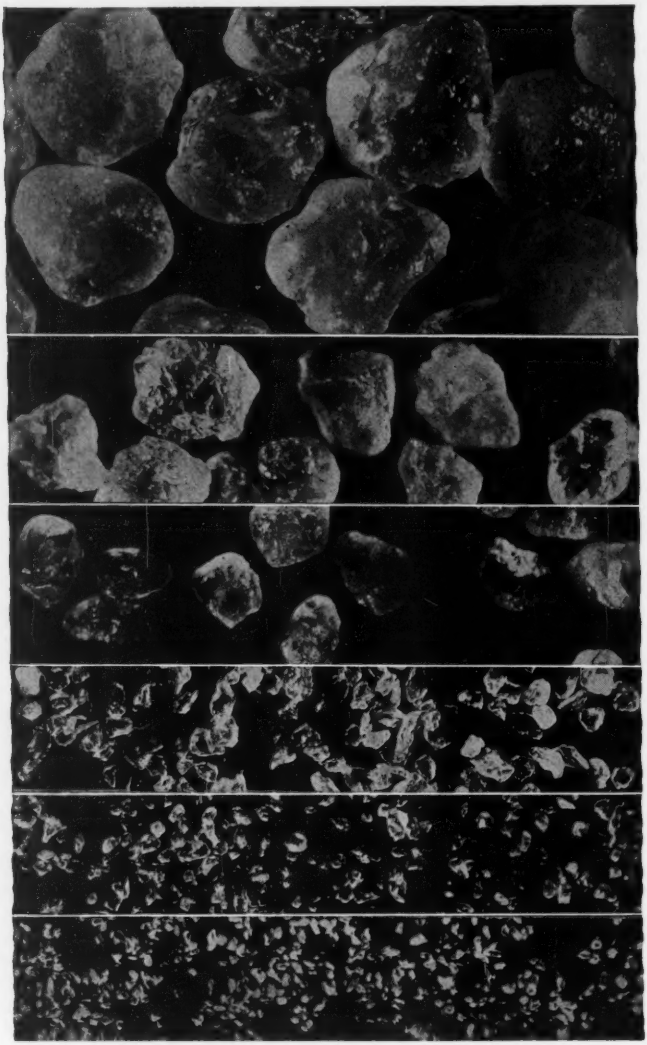
FIG. 1.—Mechanical composition of soil material from profile horizons at stations A, B, C and D, Cape Cod, Massachusetts. All stations were located in an area of active dunes; the profiles contain buried soil layers composed of fine-textured material.

laminations in the fine textured layers were noted in the Cape Cod dunes and also in a dune examined in Michigan. These are illustrated in plate 4, figures B and C. The dark-colored laminations represent organic matter.

A striking feature of the coarse dune sands of Cape Cod is their uniformity; they contain a very high percentage of particles in the 1.0–0.5 mm. class and a very low percentage in the smaller size classes. This is particularly well illustrated by the mechanical analyses of the uppermost and also the deepest horizons at stations A, B, C, and D, shown in figure 1. It may be recalled that Westgate (1904) reported 77.0 per cent of a fairly representative sample of Cape Cod sand to consist of material in the 1.0–0.5 mm. size class. As a rule 70 per cent, or more, of the material falls in this class. It is believed by the writer that there may be two explanations for this condition. In the first place a relatively sharp break is to be expected at the size class where average maximum suspension competency of the wind begins. Applying this idea to the situation at hand, it may be assumed that when particles smaller than 0.5 mm. are formed they are soon picked up by winds and removed. A second possibility is that the particles produced as a result of break-up of the coarse sand grains in transport are for the most part small, less than 0.10 mm. in diameter. This is to be expected because the impact forces resulting from sand grains striking each other must be relatively slight owing to the small mass and low velocity of the grains. The velocity with which coarse sand grains are moved along the ground surface is certainly quite low. The fact that quartz is characterized by a high degree of hardness, conchoidal fracture and lack of cleavage appears to be a further reason why the products of break-up of coarse sand in transport may consist for the most part of relatively fine particles.

The coarse sands of Cape Cod exhibit another peculiarity. Examination of the mechanical analyses of material from various horizons at stations A, B, C, and D (fig. 1) shows that not only does the highest percentage fall in the 1.0–0.5 mm. size class but that the second highest percentage falls in the 2.0–1.0 mm. class. This distribution in size classes conforms to the generalization cited in the review of literature, namely that "... if dune sands are separated into size classes and the percentage of each class determined it will usually be found that the second largest percentage falls on the coarser side of the largest percentage." It may be pointed out that this generalization seems to hold fairly well for Cape Cod dune sands (material presumably transported for the most part by traction) with some exceptions of material which underlies layers of relatively fine-textured particles (material presumably transported in suspension by winds). The dune sands from the Michigan locality (station F, fig. 2) present a different situation. Most of the particles fall in the 0.5–0.25 and 0.25–0.10 mm. classes.

Inspection of mechanical analysis data for the buried soil layers in Cape Cod profiles (station A, horizons 2, 3, and 4; station B, horizons 2 and 3; station C, horizon 3; station D, horizon 2; station E, horizon 4) reveals that in all cases 50 per cent or more of the material falls in size classes smaller than 0.5 mm. In these horizons the percentage of material in size classes smaller than 0.10 mm. varies from as low as 30 per cent to as high as 75 per cent. Only horizon 3 at station B contains more than 50 per cent of material smaller than 0.05 mm. In an earlier section it was pointed out that Udden (1898) Stebutt (1930) and Smith and Fraser (1935) all regarded loess particles as generally falling within the size limits of about 0.06 to 0.01 mm. Judged by this standard the material in the buried soil layers is not loess. It does not necessarily follow, however, that it was not transported in suspension by winds. Tarr and Martin (1913) reported the accumulation of "loess soil" or "eolian silt" in forest stands near Chitina, Alaska. The deposit of wind-transported material, containing



Photomicrographs showing soil separates from horizon 1, station A. The size classes represented are, from top to bottom, 2.0–1.0 mm., 1.0–0.5 mm., 0.5–0.25 mm., 0.25–0.10 mm., 0.10–0.05 mm., and less than 0.05 mm. Particles in the first three size classes are rounded, in the last three angular. Magnification 20×.

several generations of tree stumps, consisted of very angular particles varying in size from 0.5 to 0.03 mm. Tarr and Martin attributed the coarseness of the particles to nearness of the source material and the violence of the winds. In the Cape Cod area both of these conditions are present. No average wind velocities, based on actual records, are available for the specific area under consideration. However, so far as annual averages are concerned, these probably would be but slightly different from those recorded at other southern New England coastal stations. At Nantucket, Massachusetts, the annual average wind velocity is 13.3 miles per hour, ranging from a monthly average of 15.1 miles in February to 11.1 miles in August. The buried soil layer in the Michigan dune contained a higher percentage of fine particles than the layers above and below. In this respect it showed the same trend noted in buried layers in the Cape Cod dunes.

As pointed out in the section on laboratory investigations, particles smaller than 0.10 mm. from Cape Cod are characteristically angular. This is illustrated in plates 2 and 3. The sharp angularity of these particles points quite strongly to transport by suspension in wind. Small angular particles are, by virtue of their relatively large surface area, admirably adapted to this type of transport. Further a high degree of angularity in wind-blown particles would be expected only in cases where they were carried in suspension or where the movement by traction was short in time and space.

As a rule the content of heavy minerals (specific gravity > 2.680) in the buried soil layers is less than that of the coarse-textured material above and below. This is shown in figure 4. Coarse-textured material moved by traction generally contains more than 3.0 per cent of heavy minerals and fine-textured material transported in suspension by winds generally contains less than 3.0 per cent. The evidence obtained by the writer on this point agrees with the views of Smith and Fraser (1935), and others.

Moisture equivalent values were found to bear a direct relationship to the percentage of fine material present (fig. 5). Values for the fine-textured material from buried soil layers usually ranges from about 5.0 to as much as 20.0 per cent; in normal dune sands the moisture equivalent is generally less than 2.0 per cent. The relatively high values for soil material from the buried layers in part reflects the degree of dispersion of the inorganic matter and in part the presence of organic matter.

The nature of the buried layers of fine-textured material has been discussed in the light of both field and laboratory examination. There remains for consideration the question as to how the strata of fine-textured material originated. Several kinds of evidence bear on the problem.

Field relations of the buried strata demonstrate that the material was wind-laid and not water-laid. The layers are not horizontal but follow the irregularities of the earlier land surfaces. Strata which formed continuous layers over old dune slopes and ridges have been observed. In addition, the mechanical composition, the shape of the particles, and the content of heavy minerals in the fine-textured material all lead to the conclusion that it was transported in suspension by wind.

The hypothesis that vegetation was responsible for the accumulation of the fine material was early suggested to the writer when plant remains were invariably found in the deposits. It is a well-recognized fact that vegetation, particularly forest growth, is highly effective in reducing wind velocities. Equally well recognized is the fact that a decrease in wind velocity results in a decrease in carrying power. It is a certainty that wind carrying in suspension fine particles picked up from bare dune sands will drop some of the material when they encounter an obstacle such as a forest. As the wind-blown particles accumulate they would gradually bury the organic matter of the forest floor. It seems probable that this process may result in the dark-colored lamina-

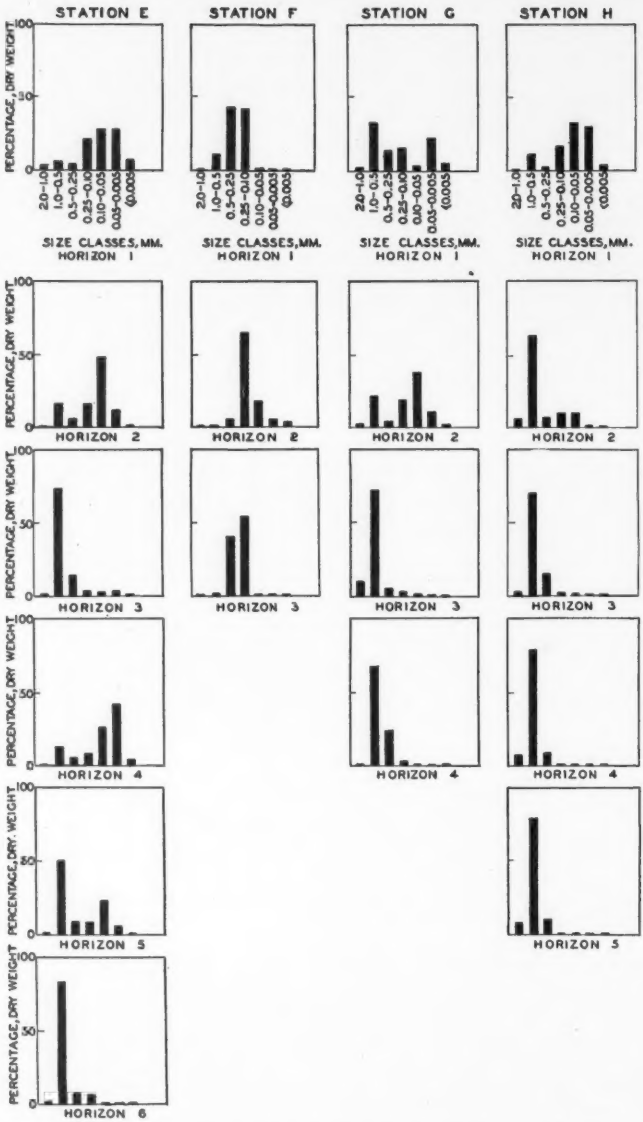


FIG. 2.—Mechanical composition of soil material from profile horizons at stations E, F, G and H. The first two profiles contain buried soil layers composed of fine-textured material; stations E, G and H were located in areas stabilized by forest vegetation. Station F, in an area of active dunes, was located near Glen Haven, Michigan; the other stations were on Cape Cod.

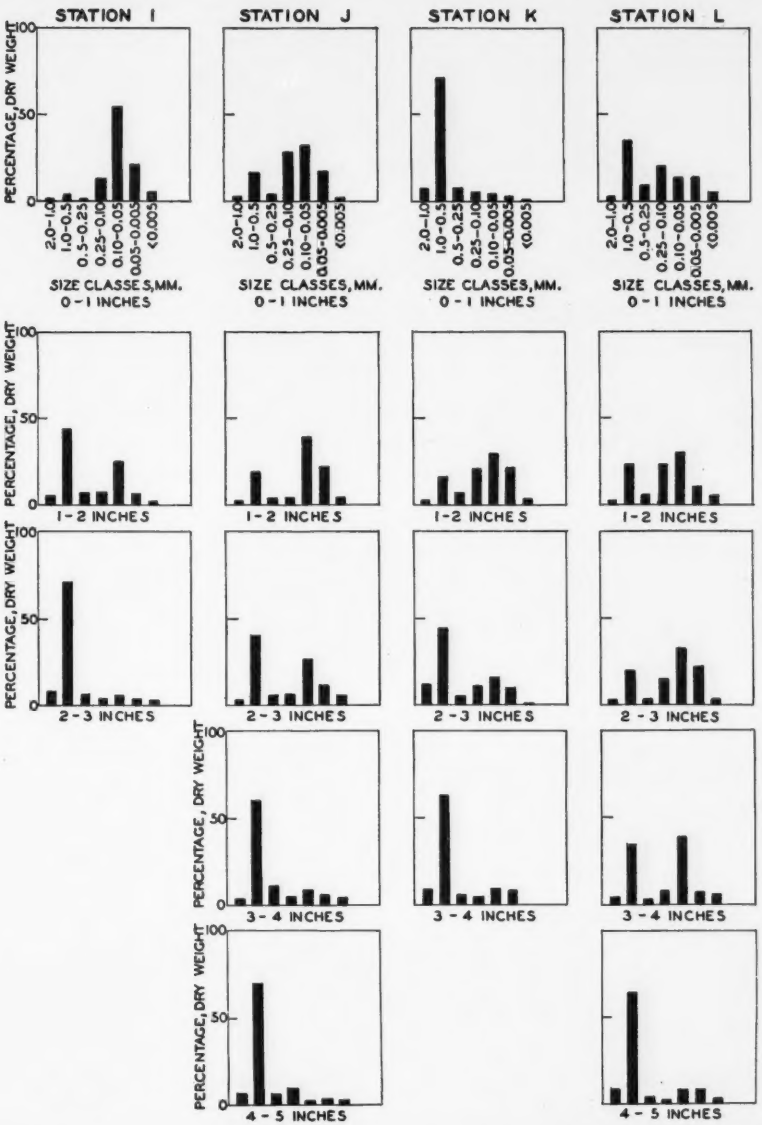


FIG. 3.—Mechanical composition of soil material taken at successive one-inch depths from stations I, J, K and L, Cape Cod, Massachusetts. These stations were located in areas stabilized by forest vegetation.

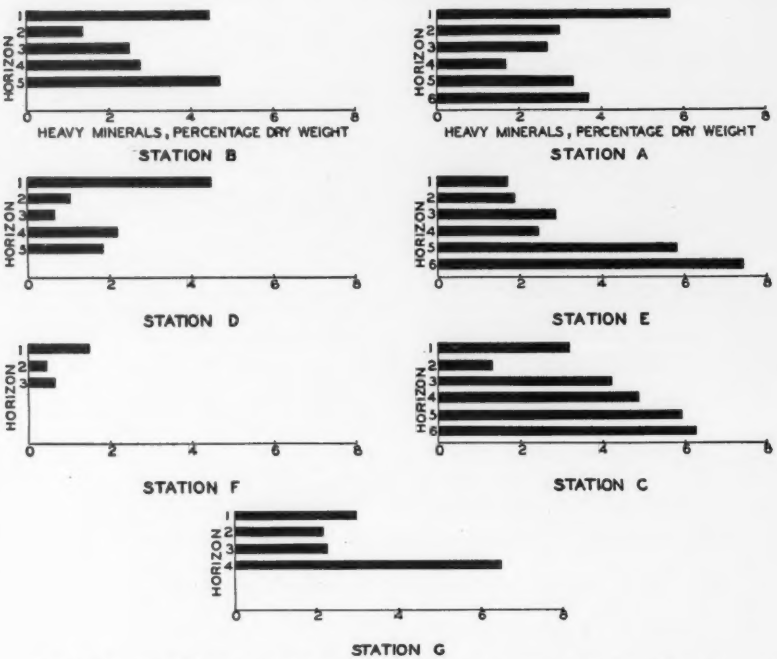


FIG. 4.—Content of heavy minerals (sp. gr. > 2.680) in soil material from profile horizons at stations B, A, D, E, F, C and G. All profiles, excepting the one at station G, contain buried soil layers.

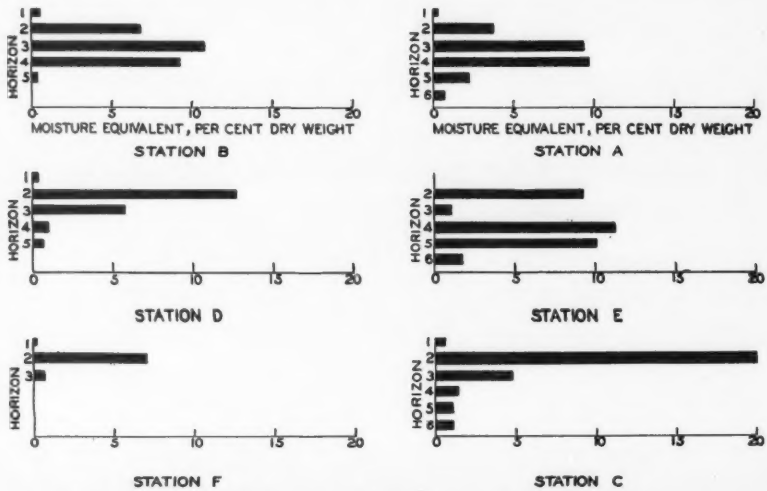
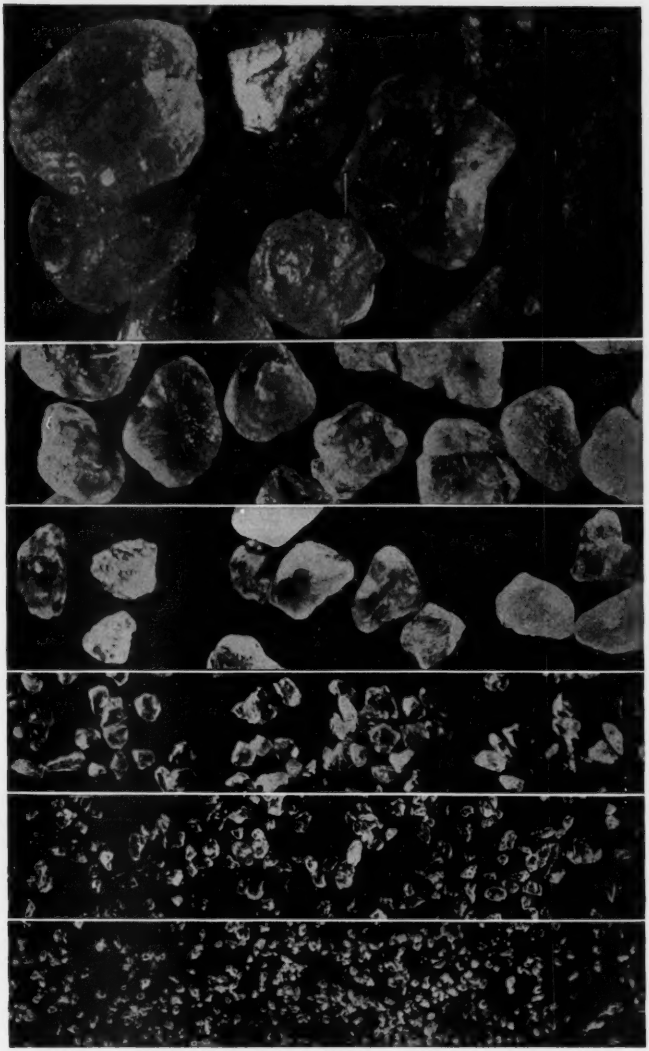


FIG. 5.—Moisture equivalent values for soil material from profile horizons at stations B, A, D, E, F and C. All these profiles contain buried soil layers.



Photomicrographs showing soil separates from the 1–2 inch depth, station I. The size classes represented are the same as in plate 2. Particles in the first three size classes are rounded, in the last two angular. Material in the 0.25–0.10 mm. class is subangular. Magnification 20×.

tions illustrated in plate 4, figures B and C.

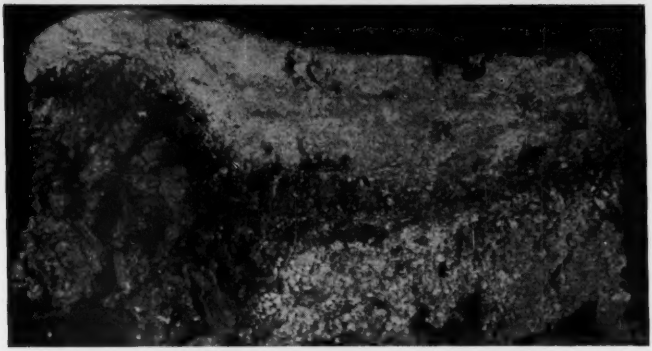
If the buried strata of fine-textured material originated in the past under the influence of vegetation it should be possible to demonstrate that fine-textured material is accumulating in forests in sand dune areas at the present time. This idea caused the writer to establish several stations in forest stands which occur in the dune area where the buried profiles were examined. At four of these stations the mineral soil was sampled at one inch vertical intervals to a maximum depth of five inches; at the others sampling was by horizons. The mechanical analyses of these samples are presented in figures 2 and 3. It is evident that in the forest stands examined fine-textured material is accumulating today as had been expected. Discovery of fine particles (mostly smaller than 0.10 mm.) of inorganic matter in bark crevices and crotches of trees affords further evidence that material transported in suspension by winds is accumulating in the forest stands at the present time. The bark of many trees was examined at various distances above the ground (up to 20 feet) and in all cases appreciable accumulations of wind-blown mineral material were found. Microscopic examination proved the material held in the bark crevices to be similar to that occurring in the fine-textured layers of the soil.

Evidently Shaler (1894) believed that fine-textured material may have developed as a result of coarse dune sand weathering in place under the influence of vegetation. He stated that, "An examination of the dunes of the Atlantic Coast has shown that the detritus of which they are composed is generally in process of division and decay. This is indicated by the fact that the materials, if taken from a site where they have evidently remained for years in repose, show the existence of much fine dust, while recent accumulations and beach-sands from which are derived may exhibit little or none of it." Two facts argue very strongly against such an interpretation in the situations investigated. Microscopic examination of the fine particles revealed that, for the most part, they consisted of quartz chips. Further, the percentage of minerals other than quartz in the shifting dune sands is too low to possibly produce any appreciable amount of fine material on weathering.

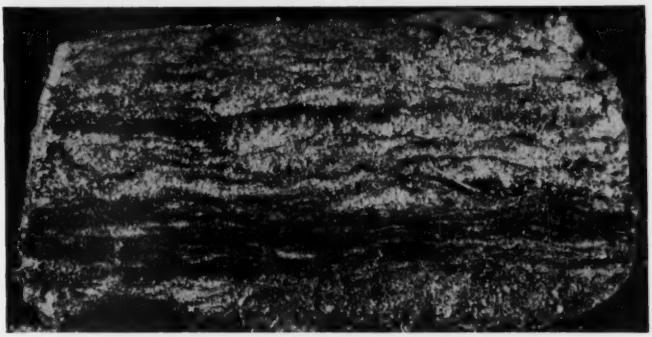
Earthworms have been credited with concentrating finely divided mineral material at soil surfaces. There appears to be no basis whatever for believing that earthworms have played a role in the development of the layers under consideration. No earthworms were observed at any of the stations where excavations were made. Further, coarse-textured sandy soils are generally recognized as unfavorable habitats for these soil animals (Olsson-Seffer, 1909, p. 111). Had earthworms been present it seems likely that the laminations illustrated in plate 4, figures B and C, would not have been preserved.

It was demonstrated in the laboratory that finely divided quartz particles are moved downward through dune sands by percolating water. Subsequent to carrying out this experiment it was found that in 1908 Olsson-Seffer mentioned that percolating water transported "fine dust" downward through dune sands. Laboratory tests by the writer showed that organic debris may serve as a filter to collect the fine material. It appears entirely possible that this same process may operate in the field. Forest stands with varying amounts of organic debris overlying the mineral soil are frequently invaded by shifting dune sands. Fine quartz particles moved downward through the overlying sand by percolating water could be filtered out and accumulated in the buried organic matter. This method of development of layers containing fine particles is suggested only as a possibility. The fact that fine-textured material is accumulating on the ground surface in forest stands today indicates another and more certain mode of origin.

Considerable ecological significance is attached to the strata composed of fine-



(A) Layer of fine textured material resting on partially decayed wood (at left of photograph) and coarse sand; this layer occurred in a buried soil body. Approximately natural size. Station C, Cape Cod.



(B) Illustrating the dark colored laminations (organic matter) in a fine tex tured layer from a buried soil body. Approximately natural size. Station A Cape Cod.

(C) Illustrating the dark colored laminations in a fine textured layer from a buried soil body. Approximately natural size. Station F, near Glen Haven, Michigan.

textured material. Shimek (1897,1908a) was one of the early writers who recognized this fact. Fine material has a very much greater water-holding capacity than ordinary dune sand and must be regarded as a more favorable medium for plant growth. It would appear that the longer a dune is stabilized by vegetation the more favorable ecological conditions become. Fine-textured material would be accumulated gradually, building up a soil of better physical properties. It is probable that even the buried layers, if close enough to the surface to be reached by roots, appreciably improve the habitat for plants.

Theoretical considerations and field observations both point to the fact that vegetation is highly important, if not in fact essential, for the accumulation of deposits of fine-textured, wind-blown material and the preservation of such deposits against wind and water erosion. The evidence obtained in the dune areas near Provincetown, Massachusetts, on Cape Cod, and near Glen Haven, Michigan, shows quite clearly that this principle applies in regions of humid climate just as well as in dry regions. The results of the present investigation serve to emphasize the rôle which vegetation, particularly forest vegetation, may play as a pedological and geological factor.

REFERENCES

ATTERBERG, ALBERT, *1905*, Über die Korngrösse der Dünensande: *Chemiker-Zeitung*, vol. 29, p. 1074.

BARRETT, W. H., *1930*, The grading of dune sand by wind: *Geol. Mag.*, vol. 67, pp. 159–162.

BEADNELL, H. J. LLEWELLYN, *1909*, An Egyptian oasis: An account of the oasis of Kharga in the Libyan desert, with special reference to its history, physical geography and water supply. John Murray, London.

BOASE, HENRY, *1822*, Observations on the submergence of parts of Mount's Bay; and on the inundation of marine sand on the north coast of Cornwall: *Roy. Geol. Soc. Cornwall, Trans.* [Penzance.], vol. 2, pp. 129–144.

BOUYOUCOS, GEORGE JOHN, *1936*, Directions for making mechanical analyses of soils by the hydrometer method: *Soil Sci.*, vol. 42, pp. 225–229.

CARROLL, DOROTHY, *1939*, Movement of sand by wind: *Geol. Mag.*, vol. 76, pp. 6–23.

CHILCOTT, E. F., *1937*, Preventing soil blowing on the southern Great Plains: *U. S. Dept. Agr. Farmers Bull.* 1171.

COBB, COLLIER, *1910*, The Landes and dunes of Gascony: *Jour. Elisha Mitchell Scientific Soc.*, vol. 26, pp. 82–92.

COFFEY, GEORGE and R. LLOYD PRAEGER, *1904*, The antrim raised beach: a contribution to the Neolithic history of the north of Ireland: *Proc. Roy. Irish Acad.*, vol. 25 (Sec. C), pp. 143–200.

COWLES, HENRY CHANDLER, *1899*, The ecological relations of the vegetation on the sand dunes of Lake Michigan: Geographical relations of the dune floras: Part 1. *Bot. Gazette*, vol. 27, pp. 95–117; 167–202; 281–308; 361–391.

CRESSEY, GEORGE BABCOCK, *1928*, The Indiana sand dunes and shorelines of the Lake Michigan Basin: *Geog. Soc. Chicago*, Bull. 8.

DAVIS, R. O. E. and H. H. BENNETT, *1927*, Grouping of soils on the basis of mechanical analysis: *U. S. Dept. Agr., Cir.* 419.

FREE, E. E., *1911*, The movement of soil material by the wind; with a bibliography of eolian geology by S. C. Stuntz and E. E. Free: *U. S. Dept. Agr., Bureau of Soils, Bull.* 68.

GERHARDT, PAUL, *1900*, Handbuch des deutschen Dünenbaues: Im Auftrage des Kgl. Preuss. Ministeriums der öffentlichen Arbeiten und unter Mitwirkung von Johannes Abromeit, Paul Bock, Alfred Jentzsch. Paul Parey, Berlin.

GRUND, A., *1906*, Die Probleme der Geomorphologie am Rande von Trockengebieten. Sitzungsberichte der Mathematisch-Naturwissenschaftlichen Klasse der kaiserlichen Akademie der Wissenschaften, Wien, vol. 115 (Abt. 1), pp. 525–551.

HEDIN, SVEN, *1904*, Scientific results of a journey in Central Asia 1899–1902: vol. 1. The Tarim River. 523 pp. Lithographic Institute of the General Staff of the Swedish Army. Stockholm.

HUNTINGTON, ELLSWORTH, *1907a.*, Some characteristics of the glacial period in non-glaciated regions: *Geological Soc. of Am. Bull.* vol. 18, pp. 351–388.

——— *1907b.*, The pulse of Asia.

HOVEY, EDMUND OTIS, *1907*, A geological reconnaissance in the western Sierra Madre of the State of Chihuahua, Mexico: *Bull. Am. Mus. Nat. Hist.*, vol. 23, pp. 401–442.
KEYES, CHAS. R., *1898*, Eolian origin of loess: *Am. Jour. Sci.* 4th ser., vol. 6, pp. 299–304.
KNOWLES, W. J., *1878*, Flint implements and associated remains found near Ballintoy, Co. Antrim: *Jour. Anthropological Institute of Great Britain and Ireland*, vol. 7, pp. 202–205.
——— *1880*, Portstewart and other flint factories in the north of Ireland: *Jour. Anthropological Institute of Great Britain and Ireland*, vol. 7, pp. 320–328.
MACCARTHY, G. R. and J. W. HUDDLE, *1938*, Shape-sorting of sand grains by wind action: *Am. Jour. Sci.* 5th ser., vol. 35, pp. 64–73.
OLSSON-SEFFER, PEHR, *1908*, Relation of wind to topography of coastal drift sand: *Jour. Geol.*, vol. 16, pp. 549–564.
——— *1909*, Relation of soil and vegetation on sandy sea shores: *Bot. Gazette*, vol. 47, pp. 85–126.
PREJEVALSKY, N., 1879, From Kulja, across the Tian Shan to Lob-Nor: Trans. by E. Delmar Morgan, with introduction by T. Douglas Forsyth. Sampson Low, Marston, Searle and Rivington, London.
RUSSELL, ISRAEL C., *1903*, Notes on the geology of southwestern Idaho and southeastern Oregon: *U. S. Geol. Survey, Bull.* 217.
SAVAGE, T. E., *1905*, Geology of Fayette County: *Iowa Geol. Survey*, vol. 15, pp. 433–546.
SHALER, N. S., *1894*, Phenomena of beach and dune-sands: *Geol. Soc. of Am. Bull.*, vol. 5, pp. 207–212.
——— *1899*, Loess deposits in Montana. *Geol. Soc. of Am. Bull.*, vol. 10, pp. 245–252.
SHIMEK, B., *1897*, Additional observations on surface deposits in Iowa: *Proc. Iowa Acad. Sci.*, 1896, vol. 4, 68–72.
——— *1903*, Living plants as geological factors: *Proc. Iowa Acad. Sci.*, 1902, vol. 10, pp. 41–48.
——— *1908a*, The genesis of loess, a problem in plant ecology: *Proc. Iowa Acad. of Sci.*, 1908, vol. 15, pp. 57–75.
——— *1908b*, The loess of the paha and river-ridge: *Proc. Iowa Acad. of Sci.*, 1908, vol. 15, pp. 117–135.
SMITH, H. T. U. and H. J. FRASER, *1935*, Loess in the vicinity of Boston, Massachusetts: *Am. Jour. Sci.*, 5th ser., vol. 30, pp. 16–32.
STEBUTT, ALEXANDER, *1930*, Lehrbuch der allgemeinen Bodenkunde. Der Boden als dynamisches System: Gebrüder Borntraeger, Berlin.
TAMM, OLOF, *1934*, En snabbmetod för mineralogisk jordartsgranskning: (Eine Schnellmethode für mineralogische Bodenuntersuchung). [German summary, pp. 249–250.] Svenska Skogsvårdsföreningens tidskrift, vol. 32, pp. 231–250.
TARR, RALPH S., *1890*, Erosive agents in the arid regions: *Amer. Naturalist*, vol. 24, pp. 455–459.
——— and LAWRENCE MARTIN, *1913*, Glacial deposits of the continental type in Alaska: *Jour. Geol.*, vol. 21, pp. 289–300.
TENSION-WOODS, J. E., *1883*, The Hawkesbury sandstone: *Jour. of the Proc. Roy. Soc. New South Wales*, 1882, vol. 16, pp. 53–116.
TWENHOFEL, W. H., *1939*, Principles of sedimentation: 1st ed.
UDDEN, JOHAN AUGUST, *1894*, Erosion, transportation, and sedimentation performed by the atmosphere: *Jour. Geol.*, vol. 2, pp. 318–331.
——— *1898*, The mechanical composition of wind deposits: Augustana Library Publications, No. 1., Rock Island, Illinois.
WESTGATE, J. M., *1904*, Reclamation of Cape Cod sand dunes: *U. S. Dept. Agr. Bureau of Plant Industry* Bull. 65.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 11, NO. 3, PP. 124–141, FIGS. 1–2, TABLES 1–2, DECEMBER, 1941

SURFICIAL DEPOSITS OF THE DESERTS OF SYRIA, TRANS-JORDAN, IRAQ AND WESTERN IRAN*

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ABSTRACT

Surficial sediments from Syria, Trans-Jordan, Iraq and western Iran may be classified into residual deposits, sheet-wash deposits, residual deposits transported by running water and wind, evaporite deposits, playa lake deposits, and eolian deposits. Residual deposits are dominant and stream deposits are absent. Except for the eolian deposits, the sediments have coarse material of granule and pebble size which consists of fresh rock, but debris of sand grain size and smaller usually consists of clay minerals and quartz. Such fine grained residuum has been cemented by calcite into aggregate grains. The aggregates disintegrate in water, or when moved by the wind, which suggests that the present desert surface generally is in a state of stability. The presence of a film of calcite coating all grains and rock fragments suggests that solution of rocks is not at present an active process over large parts of the desert surface. The large quantities of fine-grained material representing the decompositional residues appear to have been developed during a period of greater humidity than the present one.

INTRODUCTION AND ACKNOWLEDGMENTS

Investigators of the physiography of arid regions have contributed much toward an understanding of the processes of rock decay, the methods of reduction of rock surfaces, and the land forms developed in the desert areas. Only occasional descriptions exist, however, of the materials which constitute the surficial deposits. Each such deposit should indicate the agent by which it was transported to its environment of deposition, and, in some instances, the environments to which it had been previously subjected. Presumably, therefore, a general measure of the relative importance of erosive agencies now operating in the deserts of southwestern Asia can be obtained from the characteristics of the surficial sediments. In view of their possible use as indicators of former climatic conditions which obtained in these desert regions, samples of the surface deposits were collected at many widely scattered sites (fig. 1) by Dr. Henry Field during 1925 and 1926 and as leader of Field Museum Expeditions of 1927, 1928 and 1934.

Through the kindness of Mr. Clifford C. Gregg, Director, Mr. H. W. Nichols, Curator of Geology, and Dr. Henry Field, Curator of Physical Anthropology of Field Museum of Natural History, the collected sediments were made available for study. The writer takes this opportunity to thank these gentlemen for their interest and counsel.

Grateful acknowledgment must also be made to the Iraq Petroleum Company for inviting the Field Museum Expedition of 1928 to accompany the Desert Survey Party west of Rutba and for granting permission to read Dr. E. W. K. Andrau's unpublished manuscript based on geological observations recorded at that time. Dr. Andrau's cooperation is also greatly appreciated.

The governments of Syria, Trans-Jordan, Iraq and Iran facilitated the work of the expeditions in every possible manner.

The place names conform to the spelling adopted by the Permanent Committee on Geographical Names of the Royal Geographical Society of London. As the question of orthography is by no means settled and many names are not yet included in the published lists of the Society, standard practice as adopted by

* Published with the permission of the Director, Field Museum of Natural History.

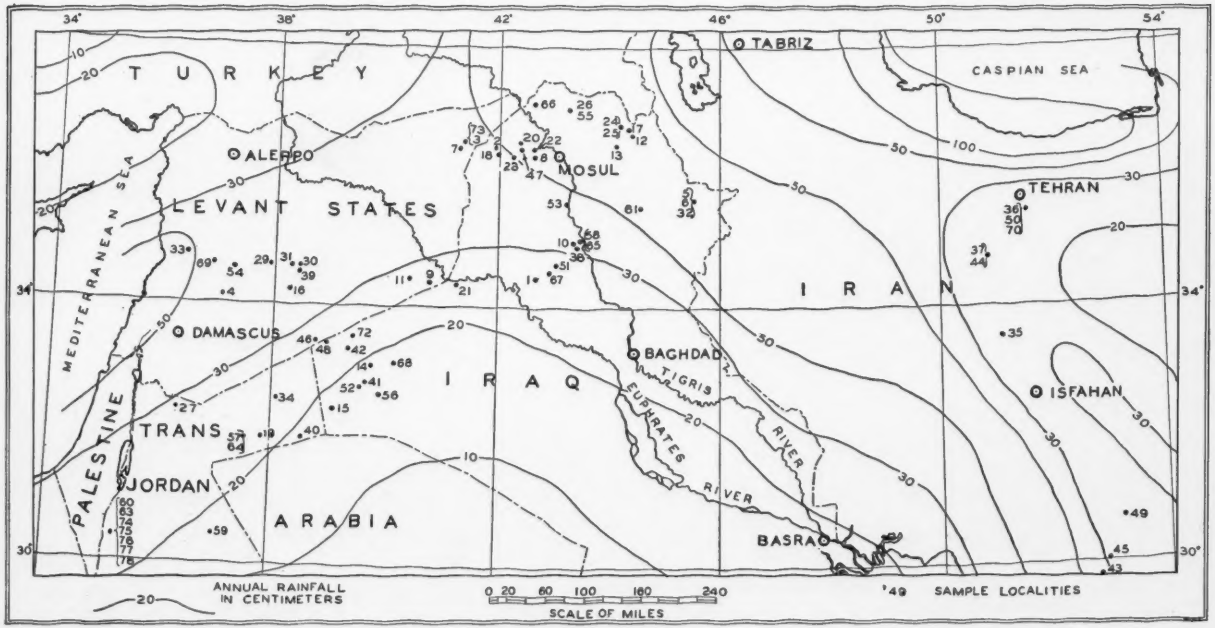

FIG. 1.—Map of the general area covered by the Field Museum expeditions showing localities where surface samples were collected.

the most recent British map-makers has been used.

DESCRIPTION OF THE REGION

The portion of southwestern Asia covered by the route of the expeditions is roughly such land as borders a line extending from the boundary of Palestine and Syria to Baghdad, thence north to Mosul and then southeasterly to Tehran. Three samples were also collected about 100 miles south of Isfahan, Iran (fig. 1). Such a route traverses four general regions: (1) the coastal area adjacent to the Mediterranean which is a mountainous district receiving the greatest rainfall of any of the four regions; (2) a steppe and plateau area of considerable aridity, occupying northern Iraq and extending eastward from the base of the mountains to the borders of the Euphrates valley; (3) the Euphrates valley, a depressed area of little relief but receiving more moisture than the plateau; and (4) the mountain and basin region of upper Iraq and western Iran.

The Coastal Area.—The coastal area south of Beirut bordering the Mediterranean is one of considerable topographic relief and elevations locally exceed 7000 feet. The mountains contain slightly folded strata of Jurassic, Cretaceous and lower Tertiary ages. Such strata have been broken by a set of prominent faults trending slightly east of north. Almost all are step faults with the eastern side downthrown, and in a number of instances strata of Eocene and Jurassic ages are brought into contact. Near Damascus the strike of similar faults is generally northeast and these intersect the north-south trending group some distance to the southwest in the valley or the Jordan River. Approximately 80 miles north of Damascus, a few flows of basalt are exposed, broken by the faults previously mentioned (Dubertret 1938, Picard 1931).

The Plateau Area.—South and east of Damascus is a plateau region of steppes, the western portion of which is designated by Musil (Wright 1927) as Al-Wudiyan, and the eastern as Al Hamad. The two divisions are separated by an indefinite line which corresponds essentially with the northern part of the divide between the watershed of the Euphrates River and the streams of interior Arabia. Actually the two regions form a single plateau which rises gently to the south to local elevations of 3000 feet where it joins the Nejd. This plateau of interior drainage and saline depressions contains within it a western section of approximately 10,000 square miles covered with flows of basalt of Pliocene and Pleistocene age. The flows extend westward to the Jordan valley south of Damascus where they are terminated on the west by the faults of the coastal region previously described. The eastern portion of Al Hamad consists entirely of Eocene strata which have been warped into a great, broad trough plunging gently to the northeast under the Miocene rocks of the steppes of Iraq and the Euphrates valley. Cretaceous strata form the surface rocks at the southeastern edge of the Hamad where it joins the Euphrates valley.

North of Al-Wudiyan and Al Hamad are the steppes of Iraq which consist essentially of horizontal Cretaceous, Eocene, and Miocene strata locally flexed into folds. The strata have a gentle inclination to the Euphrates valley.

The Euphrates Valley.—The Euphrates has cut its valley in Miocene strata whose attitude is essentially horizontal. In some localities the valley is wide and in others the stream flows through narrow gorges. Along the entire length of the Euphrates numerous wadis enter as tributaries. Throughout most of the year the wadis are dry valleys but they are subject to sporadic floods which may make them impassable for periods as long as five days (Field 1940).

Upper Iraq and Western Iran.—The mountainous section of upper Iraq lies northeast of the Tigris River. The region is one of gently folded sandstones, conglomerates, and gypsum beds of Miocene and Pliocene ages. Locally the strata are capped by basalt lavas. Eastward, to-

ward Tehran, strata of progressively older age, namely Cretaceous and Jurassic, are exposed at the surface due to more intense folding, and the rocks are cut by numerous intrusions. As the folding increases in intensity there is, correspondingly, an increase in the relief and in its eastern portion the district becomes one of mountains and intermontane basins.

Rainfall.—The four regions described above are all characterized by scanty rainfall but there is a considerable range in the quantity of precipitation, most of which is received during the months of November to April (fig. 1). During this period Tehran receives 8 inches, Isfahan 3 inches, and at Seistan there is practically no rainfall. Syria along the coast receives 20 inches but toward the south in the Tih and Arabian deserts rainfall is insignificant. In the vicinity of Baghdad, rainfall is generally less than 10 inches (Kendrew 1922). Kendrew (1922) states that northwest winds are prominent in every month in Iraq which is in agreement with the observations of Field who describes the summer winds in the Euphrates valley as blowing from the northwest quadrant and descending from the plateau like "a scorching blast from a furnace." Frequently such winds transport large quantities of dust (Field 1940). Picard (1931) states that in the Judean desert the dry, hot winds begin in the month of April, and often a southwesterly gale occurs which in one hour may deposit 5 mm. of yellow loess-like dust on any exposed object.

THE SURFACE DEPOSITS

The surficial sediments collected by Doctor Field have been classified into a number of types (table 1). These are: (1) residual deposits; (2) residual deposits which have also been transported by running water, namely sheet-wash deposits; (3) residual deposits which have been transported by running water and the wind; (4) deposits formed in evaporating basins, *i.e.*, evaporite deposits; (5) playa lake deposits; and (6) eolian deposits. Classification of the sediments into the various types was based upon observations in the field and by criteria obtained through mechanical analyses and microscopic examination.

Residual Deposits.—Residual deposits, which are numerous and widespread, are characterized by considerable irregularity in the state of decomposition of the rock fragments. Some samples consist largely of those minerals which are most resistant to rock decay, whereas, others are composed of fresh, unaltered debris. In general, except for samples 9, 40, and 72 which show no decomposition to dimentions approaching .1 mm., material of .4 mm. and less, particularly in the case of limestones, consists of the resistant products of decomposition, *i.e.*, quartz and clay minerals. Particles of granule and coarser size consist chiefly of disintegrated rock fragments. The quantity of decomposed material which is found is indicated by the fact that 50 per cent of the samples have median diameters which are .4 mm. or less. Certain deposits, such as the residual products of an olivine basalt lava flow and ejecta of the same composition (sample 69), show practically no chemical decomposition. The markedly scoriaceous ejecta has disintegrated into small fragments ½ to 1 cm. in size, many of which have shred-like edges but which show no chemical decomposition. No fine-grained debris of sand dimensions or less is associated with the scoria, signifying that weathering processes other than disintegration have not been active. This is demonstrated also by the presence of fresh olivine. Actually there has been an addition of mineral matter as many fragments are coated with a deposit of calcite which may be 2 mm. in thickness. At the other extreme is sample 42, derived from a metamorphic terrain of chlorite schist and gneiss, and which consists almost exclusively of fine grained material such as quartz and limonite-stained clay particles which are the residues of decomposition. Sample 37 is a quartz porphyry. Pebbles which are present appear to be fresh in

TABLE 1. *Localities from Which Samples of Surficial Deposits Were Collected*

Sample No.	Locality	Type of Deposit
1	Near Euphrates R. about 40 mi. NE. of Haditha, Iraq	Evaporite (ancient)
2	Jebel Khatcha, above Beled Sinjar, Iraq	Eolian
3	Near Tell Brak, Syria	Residual lst.—water transported
4	Karyatein, Syria	Residual lst.—water transported
5	Desert floor Sulaimaniya, Iraq	Residual limestone
6	Desert floor Sulaimaniya, Iraq	Residual lst.—water transported
7	27 mi. W. of Balad Sinjar, Iraq	Residual shale—water transported
8	Meer Khasan, Sinjar, 40 mi. W. of Mosul, Iraq	Residual limestone
9	Wadi Rutga, Iraq, along Syria and Iraq boundary	Residual (disintegrated) lst.
10	Along Tigris R. about 10 mi. N. of Baiji, Iraq	Eolian
11	Near Wadi Rutga, eastern border of Syria	Lag gravel
12	Rowandiz gorge, northern Iraq	Residual shale-water transported
13	Near Shaklawa, 80 mi. E. of Mosul, northern Iraq	Residual lst.—water and wind transported
14	Wadi Al Hatal, about 20 mi. W. of Rutba	Residual limestone
15	Desert floor, 60 mi. SW. of Rutba	Residual lst.—water transported
16	Desert floor, about 20 mi. S. of Palmyra	Residual shale—water transported
17	Wadi Rowandiz, Iraq, 20 mi. N. of Ruwandiz	Eolian
18	Desert floor near Balad Sinjar, Iraq	Residual limestone
19	Desert floor, airplane landing ground "J" Syria, 130 mi. SE. of Damascus	Residual lst.—water and wind transported
20	Jebel Golat, about 50 mi. NW. of Mosul, Iraq	Residual lst.—water transported
21	Wadi El Quaim at Euphrates R., NW. Iraq	Residual lst.—water and wind transported
22	Desert floor near Tall Afar, Iraq	Residual limestone
23	Desert floor 30 mi. W. of Mosul, Iraq	Residual lst.—water transported
24	Baradost Mountain, about 5 mi. N. of Ruwandiz, Iraq	Residual shale—water transported
25	Baradost Mountain, 5 mi. N. of Ruwandiz, Iraq	Eolian
26	Zawita Gorge, near Amadia, northern boundary of Iraq	Residual shale—water transported
27	Wadi Jemel, Syrian desert	Residual shale
28	Wadi Shomar, Syrian desert	Residual lst.—water transported
29	Desert floor, about 20 mi. W. of Palmyra, Syria	Residual limestone
30	Desert floor, about 5 mi. N. of Palmyra, Syria	Eolian
31	Desert floor, about 10 mi. NW. of Palmyra, Syria	Residual lst.—water and wind transported
32	Desert floor, Sulaimaniya, Iraq	Residual limestone
33	Desert floor, Lebanon Mts. 40 mi. E. of Tripoli, Syria	Residual crystalline
34	Wadi Ruwaishid, 20 mi. NE. of Burqa, Syria	Eolian
35	Desert floor 80 mi. NW. of Isfahan, Iran	Residual limestone
36	Salt marsh near Qum SW. of Tehran, Iran	Playa lake
37	Salt marsh near Qum SW. of Tehran, Iran	Residual crystalline
38	Tigris R. valley at Baiji, Iraq	Residual limestone
39	Desert floor Palmyra, Syria	Residual lst.—water transported
40	Wadi Ruwaishid, 20 mi. NE. of Burqa, Syria	Residual (disintegrated) lst.

TABLE 1—*Continued*

Sample No.	Locality	Type of Deposit
41	Desert floor 65 mi. W. of Rutba, Iraq	Residual cryst.—water transported
42	Desert floor between Rutba and Jebel Tenf, Iraq	Residual crystalline
43	Desert floor near Shiraz, SW. Iran	Residual limestone
44	Desert floor near Qum 80 mi. SW. of Tehran, Iran	Residual lst.—water transported
45	Desert floor near Sivand, SW. Iran	Residual limestone
46	Jebel Tenf, along Syria-Iraq boundary	Evaporite
47	Desert floor 22 mi. E. of Balad Sinjar, Iraq	Playa lake
48	Desert floor 16 mi. E. of Jebel Tenf, Iraq	Residual lst.—water transported
49	Desert floor at Deh Bid, southern Iran	Residual limestone
50	Salt marsh near Qum SW. of Tehran, Iran	Residual cryst.—water transported
51	Wadi Tartar 30 mi. SW. of Biti, Iraq	Evaporite
52	Desert floor near Al Jidd, W. of Rutba, Iraq	Playa lake
53	Tigris R. valley at Ashur, Iraq	Residual limestone
54	Desert floor midway between Homs and Palmyra, Syria	Residual cryst.—water transported
55	Zawita Gorge, near Amadia, Iraq	Residual shale
56	Wadi Hauran 40 mi. SW. of Rutba, Iraq	Lag gravel
57	Mudflat, airplane landing ground "H" 120 mi. SE. of Damascus	Eolian
58	Sandy desert 20 mi. N. of Baiji, Iraq	Playa lake
59	Deposit in old reservoir near Bayir Wells, eastern Trans-Jordan	Playa lake
60	Desert floor Petra, Trans-Jordan	Playa lake
61	Stream bed, 30 mi. NE. of Kirkuk, Iraq	Residual limestone
62	Marl from desert basin, locality unknown	Residual limestone
63	Deposit in old reservoir near Bayir Wells, eastern Trans-Jordan	Playa lake
64	Desert floor landing ground "H" 120 mi. SE. of Damascus	Eolian
65	Sandy desert 20 mi. N. of Baiji, Iraq	Eolian
66	Desert floor, Zakho, Iraq	Residual crystalline
67	Desert floor, near Wadi Tartar, 60 mi. NE. of Haditha, Iraq	Residual limestone
68	Wadi Abailli near Rutba, Iraq	Residual limestone—wind transported
69	Desert floor, south of Homs, Syria	Residual crystalline
70	Salt marsh, near Qum, SW. of Tehran, Iran	Evaporite
71	Desert floor, locality unknown	Residual limestone
72	Desert floor 50 mi. NW. of Rutba, Iraq	Disintegrated limestone
73	Jebel Brak, along Syria-Iraq boundary	Residual limestone
74	Desert floor Petra, Trans-Jordan	Eolian
75	Desert floor Petra, Trans-Jordan	Eolian
76	Desert floor Petra, Trans-Jordan	Eolian
77	Desert floor Petra, Trans-Jordan	Eolian
78	Desert floor Petra, Trans-Jordan	Playa lake

the hand specimen, but in thin section the feldspars are seen to be kaolinized. Most of the sample is fine grained debris which clearly consists of decomposed feldspars. Particles smaller than .4 mm. in diameter consist of the products of decomposition such as quartz, clay aggregates, and flakes of limonite. Sample 33 is a diorite which has been distinctly altered chemically. None of the pebbles is fresh and the fine material is stained with limonite from decomposition of the

ferro-magnesian minerals. There is, however, a noteworthy persistence of pyribole in the fine sizes of less than .1 mm. in diameter. Sample 66 is an arkose cemented with a calcareous cement. This material consists largely of equal proportions of quartz and orthoclase which have disintegrated into fine sizes without any significant chemical change. In some samples of residual limestones no fragments of rock larger than granules are present, and these are commonly particles of flint coated with a layer of calcareous clay. Most of the material of granule or sand size consists of buff or gray colored aggregates of quartz and clay minerals cemented together by the clay and some calcite. Limonite is commonly present as small, irregularly-shaped flakes cemented to the aggregates.

Many of the residual limestone deposits do contain pebbles and commonly such pebbles have surfaces of marked irregularity (Rillensteine). Megascopically such irregular surfaces appear to be due to small excrescences generally less than 3 mm. in height. Under the microscope, the projections prove to be the remaining less soluble portion of the pebble and their elevation is due to solution of the surrounding rock material (Loudermilk and Woodford 1932). Other limestone pebbles do not weather in such a manner and instead develop flat, facetted surfaces which have been described by Bryan (1929) from the arid districts of the United States. Sample 73 contains pebbles which are cleavage rhombs of calcite. Such rhombs are unaltered, only slightly pitted and have sharp edges. Andrau (1928) reports at Tel Abailie an outcrop of a siliceous limestone with vugs containing calcite, and the calcite crystals are strewn over the ground surface where the rock has been weathered.

Residual deposits of shale consist of pebbles of calcareous shale, but the granule and fine sizes consist of aggregates of clay particles cemented with calcite. Such particles readily disintegrate when moistened with water. Apparently the shale was decomposed into clay particles which were later cemented into aggregates.

Residual deposits are characterized by cumulative size frequency curves which are nearly straight lines with slopes indicating that the samples have not been transported from their place of accumulation. The poor sorting is well demonstrated by the curves for the residual limestones, which are the most abundant deposits, and is reflected in the phi-quartile deviation ($QD\Phi$) which ranges from 1.37 to 2.95 and averages 2.08 (table 2). Similar large values for $QD\Phi$ are obtained for all of the residual deposits. For shale the values range from 1.25 to 2.02, the lower $QD\Phi$ being the result of the poorer cementation of the shale and the consequent more rapid breakdown into small sizes. The $QD\Phi$ for residual deposits of crystalline rocks ranges between 1.72 and 2.65, averaging 2.12 which approaches the average value of 2.08 for the limestones. An average $QD\Phi$ for all the residual deposits is 2.05. The fact that most of the residual deposits have a similar $QD\Phi$ is significant since it indicates that in an arid environment weathering tends to produce fragments of uniform size distribution irrespective of the kind of rock or the size of the minerals constituting the rock. The phi-quartile skewness ($Skq\Phi$) for limestones which have been considerably decomposed shows a wide range from $-.970$ to $+.160$, whereas, for those which have been dominantly disintegrated the range is from $+.1$ to $+.652$. In the case of shales the $Skq\Phi$ ranges from $+.070$ to $+.373$ and for crystalline rocks the range is from $-.620$ to $+.412$. The variation in skewness does not show any tendency to remain in one order of magnitude. Nevertheless, in those deposits where much of the fine material is removed by solution, the cumulative size frequency curve is skewed in a negative phi direction (toward the coarser sizes), and in those rocks which have a fine-grained residuum, as in the case of argillaceous shales or limestones, the curve is skewed in a positive phi direction.

Deposits Resulting from Sheet-Wash.—

TABLE 2. *Significant Figures in Size Frequency Distribution*

Sample No.	Type of Deposit	Q_1 (mm.)	Md. (mm.)	Q_3 (mm.)	$QD\Phi$	$Skq\Phi$
5	Residual limestone	15.000	2.000	.255	2.95	+.035
8	" "	4.300	1.100	.295	1.97	−.023
14	" "	1.250	.264	.045	2.38	+.160
18	" "	1.280	.421	.135	1.60	+.025
22	" "	6.300	.770	.187	2.50	−.462
29	" "	7.600	.418	.158	2.80	−1.380
32	" "	8.700	1.700	.375	2.27	−.080
35	" "	20.750	8.000	2.550	1.50	+.141
38	" "	.750	.187	.088	1.57	−.455
43	" "	8.100	.930	.235	2.58	−.565
45	" "	.740	.073	.028	2.37	−1.000
49	" "	1.800	.540	.174	1.68	−.043
53	" "	.470	.162	.058	1.50	−.020
61	" "	.385	.155	.057	1.37	+.088
62	" "	.750	.160	.036	2.18	−.035
67	" "	4.400	1.500	.440	1.63	+.112
71	" "	2.350	.260	.114	2.19	−.970
73	" "	5.500	1.000	.169	2.45	+.060
9	Residual (disintegrated) limestone	6.300	1.760	.430	1.93	+.100
40	" " "	1.820	.550	.108	2.05	+.315
72	" " "	6.800	2.140	.275	2.32	+.652
27	Residual shale	2.180	.940	.370	1.25	+.070
55	" "	21.700	13.500	5.300	2.02	+.373
33	Residual crystalline rock	10.400	1.070	.258	2.65	−.607
37	" " "	3.700	1.070	.265	1.95	+.412
42	" " "	3.100	.980	.285	1.72	+.060
66	" " "	4.300	.590	.192	2.25	−.620
3	Residual limestone—transported by water	.330	.103	.041	1.50	−.210
4	" " "	6.700	3.820	1.680	1.00	+.190
6	" " "	.470	.225	.122	.95	−.082
15	" " "	.360	.148	.064	1.25	−.300
20	" " "	1.200	.495	.127	1.60	+.342
23	" " "	.158	.082	.037	1.05	+.100
28	" " "	1.080	.520	.255	1.03	−.010
39	" " "	.518	.226	.104	1.15	−.014
44	" " "	.522	.190	.055	1.60	+.170
48	" " "	1.450	.640	.284	1.15	0
41	Residual crystalline rock—transported by water	2.950	1.220	.680	1.08	−.210
50	" " "	.590	.265	.068	1.55	+.410
54	" " "	3.180	.250	.082	2.62	−1.020
7	Residual shale—transported by water	.185	.070	.022	1.58	1.400
12	" " "	.530	.270	.145	1.86	−.035
16	" " "	.440	.248	.152	.78	−.053
24	" " "	1.950	.800	.205	1.62	+.342
26	" " "	1.200	.560	.188	1.33	+.130
13	Residual limestone—transported by water and wind	.400	.170	.064	1.35	+.090
19	" " "	.980	.355	.230	1.05	−.403
21	" " "	.290	.176	.085	.90	+.170
31	" " "	.267	.192	.125	.53	+.078
68	" " "	.810	.520	.370	.58	−.060

TABLE 2—*Continued*

Sample No.	Type of Deposit	Q_1 (mm.)	Md. (mm.)	Q_3 (mm.)	QDΦ	SkqΦ
46	Evaporite	18.700	8.200	2.450	1.45	+.295
51	"	4.500	1.650	.225	2.18	+.713
70	"	.290	.105	.056	1.20	−.170
36	Playa lake	.160	.125	.093	.40	+.045
47	" "	.140	.073	.033	1.03	+.110
52	" "	.275	.210	.147	.45	0
58	" "	.355	.200	.133	.70	−.110
59	" "	.190	.150	.118	.35	0
60	" "	.460	.350	.265	.40	0
63	" "	.200	.150	.118	.40	−.025
78	" "	.437	.330	.255	.40	−.008
2	Eolian deposits	.295	.225	.162	.43	+.045
10	" "	.183	.155	.125	.28	+.040
17	" "	.300	.220	.167	.43	0
25	" "	.288	.220	.160	.42	+.035
30	" "	.227	.205	.164	.22	+.043
34	" "	.195	.146	.088	.60	+.163
57	" "	.490	.300	.214	.60	−.105
64	" "	.590	.310	.195	.80	−.123
65	" "	.295	.157	.108	.71	−.180
74	" "	.350	.300	.240	.30	+.052
75	" "	.355	.300	.240	.30	+.045
76	" "	.315	.240	.182	.41	0
77	" "	.320	.210	.150	.55	−.042
11	Lag gravel	2.700	.670	.450	1.29	−.709
56	" "	2.800	1.740	1.000	.75	+.057

Certain deposits have many of the characteristics of residual accumulations but they also indicate that they were transported and deposited in their present site by running water. Such deposits are interpreted as resulting from sheet-wash. They contain pebbles which are angular to subangular in shape but the angularity is less than that of residual deposits. Most of the samples consist of fragments of one rock type as in the case of residual deposits, but some contain a mixture of several different rocks. In such instances material from several sources has been carried to one locality for deposition. The bulk of the material constituting these deposits is finely divided and, in those instances where pebbles occur, the grains of fine sand and silt dimensions are less decomposed than in the case of residual deposits *per se*. For example, sample 48 contains clear calcite, halite, and selenite in the .1 mm. size along with the insoluble clay and quartz fractions of the limestone. Other samples consist almost entirely of the decompositional residue of rocks, *i.e.*, quartz and clay, re-cemented into aggregates by the clay and calcite. Both types of deposits, those consisting of pebbles and fine-grained material, and those consisting of fine-grained material alone, are poorly sorted; but the deposits which contain both coarse and fine material are not as numerous. Such is to be expected since the fine-grained debris was separated from the coarse particles by the moving water and deposited without further segregation as the flood subsided and the water was absorbed in the soil.

The effect of short transportation by water upon a residual deposit is reflected in the average value of the QDΦ which is lower in magnitude than that of a corresponding residual deposit. For sheet-wash transported limestones, the range is from .95 to 1.60 and averages 1.23; for

crystalline deposits the range is from1.08 to 2.62 and averages 1.75; and the values for fine clastics range between .78 and 1.86 and average 1.41. The average QDΦ for all of the sheet flood deposits is 1.37 which is considerably less than that of the residual deposit. The SkqΦ for sheetwash deposits is variable and no particular trend is observable (table 2).

Residual Deposits Transported by Running Water and Wind.—A few deposits bear evidence of having been transported short distances by running water and later slightly re-sorted by the wind. All of the samples obtained are limestones and consist largely of disintegrated fragments with smaller quantities of decomposed material. The pebbles which are present have rounded corners and edges and commonly have smooth surfaces, but some show the typical solution fluting observed in limestone pebbles of the residual deposits. None of the pebbles shows any indication of having been blasted by windblown sand. The fine sizes consist of rounded or ellipsoidal-shaped grains of calcite and quartz and their surfaces are slightly pitted by sandblasting. Aggregates of quartz and calcareous clay are also abundant, but their abundance is inversely proportional to the density of the matte surface on the quartz grains. Such a relationship is to be expected, for as transportation increases the tendency for such aggregates to disintegrate should also increase. In sample 19, part of the material of silt and clay size has been sorted out and swept away by the wind so that the coarser material has been concentrated proportionately. In other localities the wind has not been effective in the removal of large quantaties of silt and clay, and in some instances actual addition of fine-grained material has occurred. Sample 68 contains crystals of calcite which in some instances have sharp, crystal terminations or consist of angular cleavage rhombs. The clear surfaces and sharp edges indicate lack of extensive transportation and an absence of sandblasting by the wind. On the other hand, the fine material of sand size consists of fragments of limestone, sandstone, and quartz which are well rounded and have matte surfaces. Such fine material has been transported by the wind to this locality and has been added to the deposits resulting from sheet floods.

Concentration resulting from wind action has reduced the value of the QDΦ to less than that of the deposits resulting from sheet floods. The QDΦ ranges from .53 to 1.35 and averages .88. Likewise, the average median diameter is smaller than that of the sheet flood deposits. The median diameter of the former ranges from .170 to .520 mm. and most commonly is less than .2 mm., whereas, the median diameter of the latter ranges from 3.820 to .070 mm. and is most commonly .2 to .4 mm. The effect of the wind is also apparent in reducing the skewness of the cumulative curve. The SkqΦ is rather uniform (.078 to .170) for those which are skewed in a positive phi direction. In those instances the cumulative frequency curve is skewed toward the finer sizes as a result of the addition of fine sand and silt deposited by the wind. Sample 19 is skewed in the opposite direction and indicates a concentration of coarser material by the removal of some of the finer material.

Evaporite Deposits.—Samples which are classified as evaporite deposits are 46, 51, and 70. These consist largely of the residual products of limestone which have been cemented by calcite into crusts. Such deposits appear to have been formed more by the precipitation of salts by evaporation of standing water than by evaporation of upward moving ground water. Such appears to be true in the case of 46 which consists chiefly of travertine and some halite, cementing particles of clay into thin crusts. The crusts have been broken up and their somewhat rounded edges suggest transportation. Actually, they may not have been moved since the material shows a tendency to swell and disintegrate in water and the crusts lose some of their angularity. The presence of a thin coating of calcite and the lack of clastic material, other than

minor quantities of clay, on the upper surface of the crusts further supports the view of deposition of the cementing salts from standing water rather than evaporation of ground water. Sample 51 is of somewhat different character but of similar origin. The deposit consists of finely divided quartz and clay cemented with calcite and some selenite. The cementation is largely due to the deposition of small crystals of calcite on the surfaces of which is of the type characteristic of the residual deposits (fig. 2).

Sample 70 is an evaporite deposit in which much clastic material has been cemented by deposition of calcareous cement. As in the other samples, the deposition of calcite has been largely from the top downward. This is indicated by the nature of the crusts which consist of an upper zone of fine-grained, dense travertine 2 to 3 mm. thick which is sharply

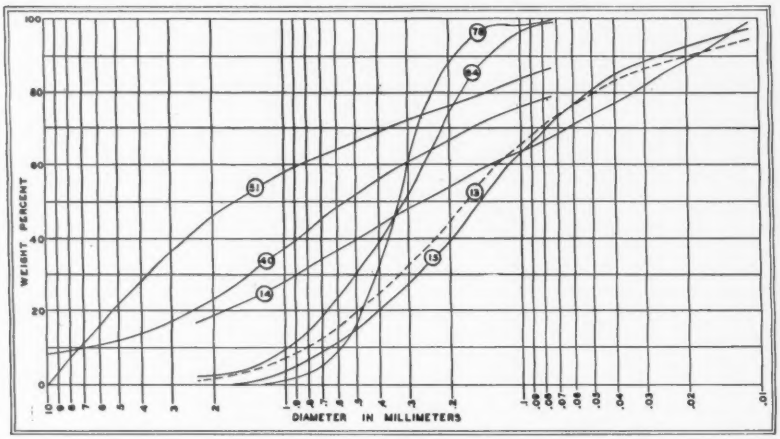

FIG. 2.—Size cumulative frequency curves of typical deposits collected. No. 13, residual limestone water and wind transported; 14, residual limestone; 15, sheet-wash deposit; 40, disintegrated limestone; 51, evaporite deposit; 64, eolian deposit; 78, playa lake deposit.

particles of clastic material, which in some instances have completely encased them, to form very irregularly shaped pellets which are covered with small crystals of calcite and selenite. Large fragments appear much the same in appearance except that extensive calcite deposition has produced a rock which is an impure crystalline limestone. Neither the large nor small fragments appear to have been transported from their locality of formation as is indicated by the small and delicate character of the calcite and selenite crystals coating the fragments, and by the cumulative size frequency curve separated from the lower zone, an aggregate of clastic material embedded in clay and cemented with calcite. In the lower part cementation is not thorough and when the crusts are wet, disintegration occurs. The clastic material consists of granules of flint, quartzite, granite, and trachyte. The fine material consists of grains of quartz and weathered feldspar, the latter somewhat stained with limonite. No transportation of the material has taken place from the salt pan since the broken crusts are soft and very angular in shape.

The size frequency cumulative curves

of evaporite deposits are characterized by a variation in the size of the median diameter. The range is from .105 to 8.2 mm. and is obviously controlled by the size of the crusts formed, by the extent of cementation, and by the size of the crust resulting from disintegration. Such deposits must therefore have the inherent size distribution properties of a residual deposit unless they have been transported from their place of origin. The QDΦ demonstrates the poor sorting characteristic of the evaporite deposits, and in the three samples ranges from 1.20 to 2.18, indicating that between the first and third quartile there are between 2.4 and 4.4 Wentworth grade units. Since the evaporites commonly consist of crusts of cemented clastic material and much fine-grained, uncemented calcareous and clastic material, the cumulative frequency curves of such deposits should show a skewness in a positive phi direction. Such is demonstrated in the case of two of the three evaporite samples, .295 and .713 respectively. One of the samples which is more thoroughly cemented is skewed in a negative phi direction (−.170). Apparently the skewness of the curve is determined entirely by the degree of cementation accomplished by the precipitated salts.

Playa Lake Deposits.—A number of samples are playa lake deposits. These are 36, 47, 52, 58, 59, 60, 63, and 78. Generally the deposits consist of the fine-grained detrital material, chiefly quartz and feldspar with only minor quantities of calcite and selenite. The individual grains are slightly rounded and moderately pitted by the sand-blasting effect of winds when the playa lakes were dry. Nevertheless, the effect of the wind upon these deposits is distinctly subordinate to that of the aqueous environment. The detritus is distinguished by the fresh and undecomposed appearance of the mineral particles, particularly if the deposit has been derived from crystalline rocks. Sample 36 consists chiefly of slightly decomposed feldspar, and minor quantities of clear, angular fragments of quartz, and a few garnets. Similar deposits derived from a limestone terrain generally consist chiefly of small limestone fragments but they may also consist of the decompositional products of limestone. Sample 59 consists almost exclusively of fragments of calcite, tests of Foraminifera, and some broken shell fragments. Well-rounded quartz grains with matte surfaces are also present, apparently having been blown into the lake by wind action. In contrast, samples 52, 58, 60, 63, and 78 consist almost entirely of angular grains of quartz, some of which are clear and some slightly stained with limonite, and a small percentage of calcite crystals. Sample 47 consists of detrital grains of quartz and clay cemented into aggregates with calcite and, more rarely, selenite. This deposit also contains much crystalline calcite which has been precipitated from solution. The sharp terminations of the calcite crystals indicate that they have experienced little or no transportation since their precipitation.

Size frequency cumulative curves of playa deposits are steeply inclined and include approximately the same size groups. This is indicated by extremes in the median diameter from .073 to .350 mm. or a range from medium to very fine sand. The arithmetical average of the median diameters is .198 mm. or very fine sand grain size. The deposits are well sorted, as indicated by the QDΦ which varies from .35 to 1.03 phi units and most commonly approximates .40 units. In the latter instance there is actually less than one Wentworth grade unit between the size of the first and third quartiles. Fifty per cent of most of the playa deposits, therefore, consists of medium and fine-grained sand. The curves are nearly symmetrical in shape as demonstrated by the SkqΦ which ranges from −.170 to +.295 but the most common occurrence is for the mean of the quartiles and the median to practically coincide, resulting in a symmetrical curve.

Eolian Deposits.—Sediments which result from the transportational and depositional action of the wind are common. Dominantly, such deposits grade from

reddish to buff color. The red color is described by Phillips (1882) as being characteristic of much of the Nefud or sand area of northern Arabia. Sample 76 illustrates the nature of the occurrence of the limonite which in grain sizes exceeding .5 mm. is a cement, making an aggregate grain from several well terminated, clear quartz crystals. Most of the samples are nearly monomineralic, and, although generally the mineral is quartz, some of the samples particularly in the coarser sizes consist of limestone and dolomite fragments. In addition to the limonite stain, the grains of every sample are coated with a thin film of calcite. The thickness of such a film may vary considerably from one which is scarcely apparent to a heavy coating. In sample 75, which consists of sub-rounded quartz grains slightly stained with limonite, an armor of minute calcite crystals covers the quartz.

The presence of the limonite stains and of the calcite crystals, coating the quartz grains, suggests that the wind recently has not been an active transporting medium. Such a conclusion is supported also by samples in which the grains of .5 mm. or less in diameter consist of quartz grains cemented into aggregates with a soft, calcareous clay. The quartz grains are predominantly rounded with matte surfaces and slightly stained with limonite, whereas, the aggregates are so poorly cemented that they would be unable to maintain their integrity under any pronounced movement by the wind.

All of the eolian deposits are uniform in the shape of the cumulative size frequency curves which are steeply inclined and symmetrical and closely resemble those of the playa deposits. The median diameter ranges from .088 to .310 mm. and is commonly about .2 mm. The QDΦ ranges from .22 to .80 and averages .46 which is approximately the same figure as in the case of playa deposits. The skewness of the curves is not great, the extremes being $-.180$ and $+.163$ phi units, but usually it approaches zero.

Only two samples of lag gravels are in the collection. In each case they are composed of residual limestone material. The pebbles are small and well worn with smooth or etched surfaces. The sand sizes are dominantly composed of well rounded calcite grains with matte surfaces, and minor quantities of similarly rounded and surfaced quartz grains. Neither sample has had all the material of silt and clay size swept away by deflation and considerable amounts of the very fine sizes remain. The QDΦ, therefore, is quite large and with the exception of residual deposits such values for lag gravels are larger than for other classes of sediments. Removal of the finely divided sediment also is reflected in increasing the skewness of the cumulative size frequency curve. But, the degree of skewness is not uniform because of its dependence upon the quantity of fine-grained material which has been removed from the deposit. In general, such deposits should show a pronounced negative SkqΦ, such as sample 11, which has a value of $-.709$. In contrast, sample 56 has had little fine material removed and has an SkqΦ of .057.

GENERAL CHARACTERISTICS OF THE SEDIMENTS

Despite the diversity in the manner of deposition of the sediments and the wide distribution of the localities sampled the deposits have certain common features. Some of these may prove to be developed typically in the desert environment and hence will be of value in the recognition of ancient desert deposits. Except for the wind-transported materials, the sediments have coarse material of granule and pebble size which consists of fresh or nearly undecomposed rock, but debris of sand grain size and smaller usually consists of clay minerals and quartz. A uniform gradation of undecomposed to completely decomposed material does not appear to exist, rather there is a sharp delineation between the decomposed materials of sand grain size and smaller dimensions, and the fresh rock of granule and pebble size. In all

instances where such relationship exists the fine-grained residuum of rock decay has been cemented by clay and calcite into aggregates of sand grain size.

There is a striking absence of sediment transported and deposited by running water. Samples gathered from the beds of wadis lack the characteristics of stream gravels but have the properties of residual deposits slightly modified by stream transportation. The previously mentioned aggregates composed of the residuum of rock decay cemented with clay and calcite constitute an appreciable part of the sediments. Yet, such aggregates are easily disintegrated when moistened, and, more rapidly so if moved a short distance by water. Simple laboratory experiments indicate that the constituent particles are carried away as a part of the suspended load in running water. Since such fine-grained material has remained in the sediments obviously the latter could not have undergone much water transportation. Other samples taken from the beds of dry wadis consist largely of material which has been deposited by wind action.

Sediments which do show some evidence of water transportation are those which cover the nearly horizontal surface of the desert floor. This fact seems to indicate that over much of this desert region the quantity of water which forms the runoff and is concentrated into channels is very small. Hörner (1936) states that in parts of Central Asia only exceptionally heavy rains result in any surface runoff. In western Asia Minor, the rainfall which is removed as runoff is chiefly as sheet-wash, the sporadic occurrence of which results in a slow rate of pebble rounding. Sediments of coarse and fine grain size are deposited together and remain until the next rain whence they may be again moved a short distance. Lack of long transportation of the sheet-wash deposits is reflected in the uniformity of rock material in any one sample. Very few of these sediments consist of fragments of several kinds of rocks, rather, most of the deposits consist entirely of debris from one type, commonly limestone, uncontaminated by sediments from other sources. Obviously such material has not been transported any appreciable distance from its locality of origin as a disintegration product.

The infrequency of surface runoff is indicated likewise by the rarity of playa lake and evaporite deposits. Only a few of the samples gathered may be so classified despite the fact that many were collected from depressions where such deposits might accumulate if given an adequate supply of water. Three samples of evaporite deposits are in the collection and each of these is representative of only a very thin accumulation of saline material. Playa lake deposits are somewhat more numerous and have little associated evaporite material other than a thin film of calcium carbonate coating the individual grains. The lack of other salts seems best explained by the absence of extensive repeated accumulations of water to furnish the proper constituents to the evaporating lakes.

The presence of numerous deposits of residual materials unaffected by any agents of transportation appears to be one of the dominant characteristics of the region under consideration. Sediments accumulating in the wadis, mountains, and flat desert floor are the products of weathering and have accumulated without addition of material from other sources or removal of much material by wind or water agencies. Over much of the desert surface, therefore, erosion must proceed at a very slow pace. Phillips (1882) notes that in the Great Red Desert of northern Arabia objects left upon the surface remain uncovered for many years. Such conditions may represent surfaces similar to the "peneplain" surfaces described by Hörner (1936) in Central Asia. He states that large sections of the "peneplain" surface seemed to have reached an equilibrium with little denudation and no accumulation.

Deflation and the accompanying deposition of eolian sediments are active, or have been active processes, and wind

deposited materials are rather common. Such deposits are found on the floors of wadis as well as on the open desert. Some of these deposits are being shifted in position at the present time and these consist of grains which are almost entirely pure quartz, well rounded, and with well developed matte surfaces. In general, such samples are derived from the northwestern portion of the area traversed by the expedition. Elsewhere, wind action appears to have been more effective formerly than at present. Such a statement appears justified in the light of existing evidence. Some of the wind-blown deposits contain grains of such soft minerals as mica which are commonly removed either by abrasion or deflation from regions where active wind transportation prevails. Many of the grains are coated with a film of limonite which would be removed by the abrasion and impact of grains common to deposits undergoing active wind transportation. Phillips (1882) calls attention to the presence, in the Nefud, of limonite coatings on the quartz grains which had been rounded by wind action and then remained at rest sufficiently long to receive a coating of limonite. In the fine sizes of some of the samples there occurs much material which consists of aggregates of quartz grains loosely cemented with calcareous clay. These aggregates are so poorly cemented that any extensive blowing about by the wind would cause them to be broken into their individual constituents. Blackwelder (1928) describes somewhat similar material, *i.e.*, aggregates of clay, in low dunes on the lee side of playas in the Mohave desert. Perhaps the best evidence of the lack of recent movement of sediments by the wind is to be found at Petra (sample 75) where a deposit of wind-blown sand consists of rounded grains of quartz with matte surfaces. Coating this surface is a thin film of limonite and superimposed upon the limonite film is an accumulation of calcite. The calcite, strictly, is not a layer, but a growth of microscopic crystals whose terminations extend outward from the grain surface. So delicate are these crystals that continued impact against other grains will readily destroy them. In order that such calcite crystals may be preserved, the surface of the desert at the locality of sampling must be one over which material is not being shifted by wind action, and must be considered for the present to be in a state of stability.

The stability of much of the desert surface appears to be demonstrated by each surface sample which, excepting a few aqueous and eolian deposits, consists exclusively of debris of one rock variety. Sheet-wash in this western Asiatic desert region is apparently incapable of transporting rock debris any great distance. The result has been little mixing of sediments such as occurs when they are derived from several sources and accumulate in one basin of deposition. Should this feature prove to be characteristic of the entire desert then the dominant agency of rock destruction is weathering in situ and other erosive agents such as the wind and running water are of minor importance. Weathering in situ over much of the Libyan desert is described by Sandford (1933) who states that south of the Sudan border concentrations of iron and manganese salts occur in a tough, dry, clay which may exceed six feet in thickness and which he believes is a form of laterite.

One feature in particular appears to be characteristic of all deposits, namely the presence of a film of calcite covering the individual grains of mineral matter, and acting as a cement in binding grains of quartz and clay together into aggregates. In some, particularly the residual deposits, the coating of calcite on the grains is heavy, whereas, in the playa lake deposits the coating is a thin film. The presence of calcite as a cementing agent does not appear to be limited to any particular variety of rock for it is present on crystalline as well as on sedimentary rocks. Similar accumulations have been recognized elsewhere and appear to be characteristic of the desert environment.

Miller (1937) describes a calcareous calcite deposit which is widespread in Nejd. White (1939) states that calcite and, to a lesser extent, apatite seem to be diagnostic of desert sediments; and Gautier (1935) reports that the mobile sedimentary deposits protect themselves directly against eolian action by the "croute calcaire." The latter develops wherever there is a deep-lying sheet of water below the alluvial bed.

The calcite coating of the grains in the samples studied is not sufficiently heavy to form crusts or a true caliche, rather, there is a tendency for the coating to be thin and to act as a cement only in binding clay particles into aggregates. The widespread occurrence of the calcite coatings precludes their growth as the result of some particular local condition but indicates that their development is characteristic of the environment of the Asia Minor desert. The immediate source of the calcite is not clearly indicated. It may be derived from the evaporation of the runoff following rains, but, more likely the source is from the evaporation of groundwater carried to the surface by capillarity. Locally the groundwater is known to be charged with calcium carbonate, and, such a condition may be widespread particularly since many of the strata are calcareous. Except for the Hamad and the area covered by basalt lavas the groundwater is generally close to the surface for Andrau (1928) reports the water table as less than 25 feet over most of the desert area west of the Euphrates. Over much of the same region wells and springs are to be found from some of which are reported maximum flows of 50,000 gallons daily.

BEARING ON FORMER CLIMATE

Several features observable in the sediments appear to reflect the generally dry climate now existent in the region but the sediments contain certain other features which appear to have resulted from a climate of greater humidity. Throughout the sampled area the rainfall varies considerably, yet despite such variation the present climate is one of sufficient aridity to develop a calcareous film on the grains of all minerals composing the surficial deposits. Even in localities such as that of sample 69 where the annual rainfall is about 45 cm., a heavy coating of calcite forms on the surface fragments. In this instance pieces of basalt are coated with a covering of calcite whose exterior appears as arborescent excrescences and whose origin is unquestionably identical with the calcite coatings previously described. The coating is not a single layer but occurs as thin laminae of .1 mm. or less in thickness whose development must result from a periodicity in accumulation of the calcite. Such periodic deposition must obviously be related to the present season of aridity, April to November, whereas the remainder of the year must be a time of no calcite precipitation or even a period of calcite solution. The resulting laminated calcite coating, therefore, must signify that the amount of rain which falls throughout the year is insufficient to entirely dissolve the deposit of calcite accumulated during the preceding season. If this is the condition in a district where the rainfall is 45 cm. annually, calcite accumulation could be even greater in those areas of less precipitation. The slight extent to which solution of calcite occurs during the moist season is illustrated by sample 73 which contains rhombs of calcite apparently unaffected by solution, yet, the locality is one which receives between 40 and 50 cm. annual rainfall. Contrasting sharply with such unweathered deposits are weathered sediments such as sample 42 which is a well weathered schist occurring in a locality where the rainfall ranges between 20 and 30 cm., and sample 53 a highly decomposed limestone in a locality of from 40 to 50 cm. of rainfall. Also, there is sample 14 from a locality of approximately 20 cm. of rainfall. The rock is a dolomite which has been actively attacked by solution to the extent that the remaining, more resistant, fragments are lace-like in appearance. Partly covering

the irregular surfaces of such fragments there is to be found a thin deposit of delicate crystals of calcite. The presence of the calcite deposit on the more insoluble portions of the dolomite is not readily explained, assuming the solution of the dolomite and precipitation of the calcite to have occurred under identical climatic conditions.

The residual deposits possess certain features which do not appear to be the result of the same processes. One such feature is the large quantity of material present which consists of the residuum of rock decay, *i.e.*, minerals which are resistant to chemical weathering. The contrasting feature is the aggregation of these residual products into grains and their cementation by calcite. Similar aggregates are present in every deposit, despite the differences in the quantity of present rainfall. Well decomposed surface sediments, such as sample 14, occur in regions of less than 20 cm. of rainfall and others which are unweathered, such as sample 69, occur in regions of nearly 50 cm. of rainfall. In each instance the coating of calcite is present over the mineral grains and the rock fragments. Since the calcite is not being removed, and is probably forming under the existing climatic conditions one must conclude that solution is not an active process on the present surface of the desert, and that carbonate rocks are not being attacked by chemical weathering. Possibly solution of the carbonate rocks occurs during the season of rainfall and later during the dry season the calcite coating is deposited from evaporating groundwater. Certain evidence exists, however, which appears to refute such an argument. Attention has already been directed to sample 69 in which some of the basalt fragments are coated with thin layers of calcite. The presence of the laminae indicates that the calcite coating is not removed annually, hence solution of the basalt must be greatly retarded or halted. Likewise, the presence of uncorroded crystals of calcite, as in sample 73, indicates lack of solution. Nevertheless the high percentage of the residual products of weathering, such as quartz and clay minerals, which is to be found in other samples undoubtedly indicates that chemical weathering has been effective. There exists, therefore, evidence which appears to be contradictory. If, however, an increase in aridity of the climate over that which had previously obtained is postulated, then manifestly the rocks could be attacked chemically during the period of greater rainfall and chemical weathering would be negligible under the present conditions. Gautier (1935) states of the Sahara that the great deep complex valleys are good evidences of the more humid climate of the Quaternary. But, the eastern side of the Libyan desert does not appear to have experienced as much humidity. Huntington (1907) describes layers of carbonaceous clay, bog iron ore, and lignite containing fossilized wood in the Pleistocene deposits of Turfan (Chinese Turkestan) a region which at present is a desert. Archaeological evidence such as the former greater fertility of Palmyrena, the former greater eastward extension of the line of cultivation in Trans-Jordan, and the remains of habitations in the Hamad in regions now waterless are cited by Grant (1938) as evidence for the existence of a climate of greater humidity. Field (1929, 1933, 1934) has also called attention to the probability of a more humid climate throughout this region during the periods of pre-historic and early historic occupation.

If such a period of humidity did exist the negligible quantities of sediments carried by, or deposited in water which were found in the area sampled, suggest that the rainfall in Iraq, Trans-Jordan, Syria and western Iran was insufficient to result in any extensive surficial runoff. Nevertheless the evidence furnished by the sediments suggests that the climate was one in which solution of the rocks was dominant in contrast to the present condition which favors precipitation of calcite. The climate, therefore, must have been more favorable for the growth of vegetation and the accumulation of groundwater, but it does not appear to have been a region which in any sense might be considered humid.

REFERENCES

ANDRAU, E. W. K., *1928*, Geology of the desert region along the Trans-Desert pipe line route, unpublished manuscript, pp. 12–40.

BLACKWELDER, ELIOT, *1928*, Notes on sedimentary deposits in the desert: *Nat. Res. Coun., Reprint and Circular Ser.*, vol. 85, p. 78.

BRYAN, KIRK, *1929*, Solution facetted limestone pebbles: *Am. Jour. Sci.*, vol. 218, pp. 193–208.

DUBERTRET, L., *1938*, Etudes sur les États du Levant sous mandat Francais: *Revue de Geog. Phys. et de Geol. dynamique*, vol. vi, pp. 269–318.

FIELD, HENRY, *1929*, Early man in North Arabia: *Natural History*, vol. 29, pp. 33–44.

———, *1933*, The antiquity of man in southwestern Asia: *Amer. Anthropologist*, N. S., vol. 35, pp. 51–62.

———, *1934*, Sulle caratteristiche geografiche dell' Arabia settentrionale: *Roy. Ital. Geog. Soc., Bull.*, vol. 11, pp. 3–13.

———, *1940*, The anthropology of Iraq, pt. I, The upper Euphrates: *Field Mus. Nat. Hist. Anth.*, ser., vol. 30, pp. 17–18.

GAUTIER, E. F., *1935*, Sahara, the Great Desert. Columbia Univ. Press. pp. 51–57.

GRANT, CHRISTINA P., *1938*, The Syrian Desert. Macmillan company, p. 53.

HÖRNER, NILS, G., *1936*, Geomorphic processes in continental basins of central Asia: *Int. Geol. Cong. XVI Sess.*, U. S. A., pt. 2, pp. 723–729.

HUNTINGTON, ELLSWORTH, *1907*, Some characteristics of the glacial period in non-glaciated areas: *Geo. Soc. Amer.*, Bull., vol. 18, pp. 351–388.

KENDREW, W. G., *1922*, The Climates of the Continents. Oxford. pp. 148–152.

MILLER, ROBERT P., *1937*, Drainage lines in bas-relief: *Jour. Geol.* vol. 45, pp. 432–438.

PHILLIPS, J. A., 1882, The red sands of the Arabian desert: *Quart. Jour. Geol. Soc.*, vol. 38, pp. 110–113.

PICARD, L., *1931*, Geological Researches in the Judean Desert. Jerusalem.

SANDFORD, K. S., *1933*, Geology and geography of the southern Libyan desert: *Geog. Jour.*, vol. 82, p. 221.

WHITE, W. A., *1939*, Mineralogy of desert sands: *Am. Jour. Sci.*, vol. 237, pp. 742–748.

WRIGHT, JOHN K., *1927*, Northern Arabia, the explorations of Alois Musil: *Geog. Rev.*, vol. 17, p. 196.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 11, NO. 3, PP. 142–144, FIGS. 1–2,
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HORNBLENDE AND MAGNETITE HEAVIES IN THE ELLENSBURG OF CENTRAL WASHINGTON

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ABSTRACT

The mineral assemblage in the Ellensburg formation is unusual in many respects. The heavies are restricted exclusively to hornblende and magnetite. The lights are essentially glass and plagioclase. All of the minerals are remarkably euhedral although evidence points to sources up to 50 miles or more from their present position. The uniform mineral content persists over an area of many hundreds, if not thousands, of square miles and may prove to be an aid in working out the stratigraphy of central Washington.

The Ellensburg formation outcrops over an area of approximately 4000 square miles in central Washington. The thicker and coarser portions lie on the eastern slope of the Cascade Range; the thinner and finer portions extend farther east over the Columbia Plateau. This paper deals with an area of approximately 500 square miles which includes the towns of Yakima and Ellensburg. This area was chosen because it contains the type localities and because here the sediments are thickest and best exposed.

The Ellensburg in this portion of the Cascades is composed of white to buff colored tuffaceous sandstones and conglomerates which have a maximum thickness of over 1500 feet. The rocks vary from extremely coarse gravels and conglomerates to thinly stratified fine sandstones and silts. Cross-bedding and torrential bedding are common. Very typical of the coarse clastics are pebbles of gray or pink hornblende andesite and large blocks and boulders of white pumice. Although the Ellensburg rests on, and is interbedded with basalts, it contains less than one per cent basalt pebbles.

Stratigraphically, the Ellensburg lies conformably on the Miocene Yakima basalts which have a total thickness of 2000 feet in this region. This portion of the Ellensburg is usually less than 100 feet thick and is overlain conformably by the Wenas basalt, also less than 100 feet thick. The Wenas basalt represents the last of the Yakima basalt flows and is distinguished from them by the presence of the intervening sediments. The main portion of the Ellensburg conformably overlies the Wenas basalt.

Structurally, all of the above mentioned rocks have been folded into a series of northwest-southeast trending, asymmetrical anticlines and synclines. The crests of these folds make prominent ridges which have crests several thousand feet above the valley floors.

PREVIOUS WORK

The Ellensburg was first described by Russell (1893) who named it the John Day formation because of its resemblance to the John Day beds of Oregon. His type localities were in the Wenas and Naches valleys—the same area embodied in this paper. He also described another locality at White Bluffs but later work (Merriam and Buwalda, 1916) has indicated that these beds probably are younger than the Ellensburg. Smith (1903) gave the name Ellensburg to these sediments when mapping the quadrangle of the same name. He states that typical exposures occur near the Normal School in the town of Ellensburg but the best exposures are along the lower course of the Yakima River west of the town of Yakima. The writer regards this locality along the Naches River as the most typical since it is agreed upon by both Russell and Smith and because it has by

far the thickest sequence and best continuous exposure. The locality near the Normal School (Central Washington College of Education) is purposely omitted from this paper as both the structural conditions and the mineral assemblage are complicated and worthy of a more detailed report than can be given here. Recent work has brought many changes in the status of the Ellensburg. Buwalda and Moore (1930) suggest, on fossil evidence, that it may be upper Miocene or lower Pliocene, in age. Culver (1937) contends that many beds now considered Ellensburg may more properly be regarded as the Pleistocene Ringold formation. The contributions of Beck, Jenkins, Hofman, Waters and Warren have provided much new information but as yet little agreement exists

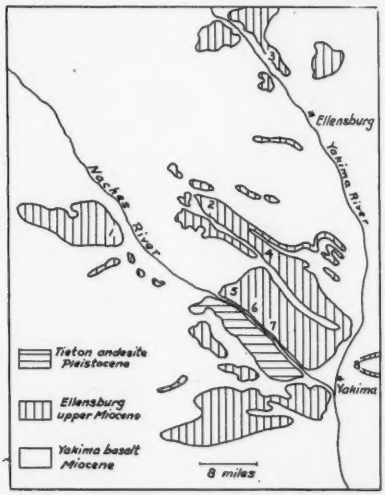

FIG. 1.—Sketch map showing sample localities and distribution of the Ellensburg. (Modified from the state geologic map of Washington.)

as to the position, structural relations and areal extent of the Ellensburg as a formation. The application of petrographic methods may help to distinguish it from the older sediments intercalated in the lower portions of the Yakima basalts or from the younger Ringold, White Bluffs and terrace deposits so abundant in this region.

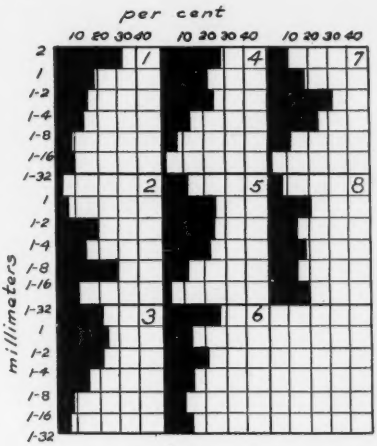

FIG. 2.—Histograms of samples 1–8 showing grade sizes.

PROCEDURE

Channel samples averaging 500 grams each were taken from the localities indicated on the map (fig. 1). Although the samples described are few in number, they are representative of a larger number of samples studied. Little would be gained by tabulating so much information in so uniform an assemblage.

Most of the sandstones can be broken by hand or by gentle rubbing with wooden blocks. Frequent inspections while breaking the samples show the progress of the disaggregation. As most of the material is of sand size, it was screened and histograms prepared of the results.

The −115 and +250 grade sizes were cleaned in dilute hydrochloric acid and separated into light and heavy fractions by means of bromoform (sp. gr. 2.75). Magnetite was separated from the other heavies and counted in proportion to the total heavies. Approximately 200 grains

were counted for the percentage composition. Fairly accurate estimates were also made by separating the heavies into a hornblende fraction and magnetite fraction by means of a magnet.

HEAVIES

The most unusual feature of the heavies is that the minerals are limited exclusively to hornblende and magnetite. All other constituents may be classified as rare or lacking. Inspection of the locality map (fig. 1) will show that although the samples were taken at 10 or 20 mile intervals, the heavies are identical in their mineral composition.

The hornblende is usually a clear lustrous black or dark green color and by transmitted light varies from clear to moderately turbid. A pale brown glass adheres to the sides of many crystals. Shapes range from perfectly euhedral with sharp prism and clinodome terminations to subangular. Inclusions consist of magnetite octahedra, small plagioclase laths and occasional stubby prisms of apatite. Optically the hornblende has the following properties:

Ng = 1.66 Z = green 2V about 62°
Np = 1.64 Y = green
X = brown

Magnetite is usually in the form of shiny octahedra, or less commonly, dodecahedra. Occasional clusters of two or more octahedra occur with brown glass as a binder.

The heavies contain some turbid material impossible to determine but this is extremely small in quantity. Hypersthene may total a few per cent of the heavies. The following is a tabulation of the percentages of the minerals in the heavies:

Sample number	hornblende	magnetite	hypersthene	turbid
1	63	32	3	2
2	90	10		
3	64	36		
4	61	39		
5	70	30		
6	76	23		1
7	68	30		2
8	81	19		

The most abundant material in the lights is a turbid to partially clear, pale brown glass with an index of 1.52. This index suggests an andesitic composition. The glass contains small crystals and dust of magnetite as well as hematite and some limonite. Next in abundance are crystals of plagioclase varying in composition between Ab 66 and Ab 78. The crystals are both zoned and twinned (Albite and Carlsbad). Often a thin clear shell or outer zone surrounds a partially turbid core. On the whole, however, the plagioclase contains but little turbid material. Brown glass adhering to many of the plagioclase crystals causes the smaller crystals to be retained in the larger grade sizes.

REFERENCES

CULVER, H. E., *1937*, Extensions of the Ringold formation: *Northwest Science*, vol. 11, No. 3 pp. 57–60.

BUWALDA, JOHN P. and MOORE, BERNARD N., *1930*, The Dalles and Hood River formations of the Columbia River Gorge: *Carnegie Inst. of Wash. Contrib. to Paleo.* No. 404, pp. 11–26.

MERRIAM, JOHN C. and BUWALDA, JOHN P., *1916–1918*, Age of strata referred to the Ellensburg in the White Bluffs of the Columbia River: *Univ. of Calif. Pub. in Geol.*, vol. 10, pp. 255–266.

RUSSELL, I. C., *1893*, A geological reconnaissance in central Washington: *U. S. Geol. Survey Bull.* No. 108, pp. 1–101.

SMITH, G. O., *1903*, Ellensburg Folio, Washington: *U. S. Geol. Survey Geol. Atlas* No. 86, pp. 1–7.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 11, NO. 3, PP. 145–147, 1 FIG., DECEMBER, 1941

A METHOD FOR THE DETERMINATION OF THE RELATIVE RADIOACTIVITY OF MINERAL GRAINS

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ABSTRACT

Mineral grains are mounted directly upon a special photographic plate, the plate exposed and developed, and the number of alpha tracks originating from each source grain counted. The number of tracks developed around each mineral grain per unit of time is an index of the relative radioactivity of the grain.

GENERAL STATEMENT

The authors recently have had occasion to make rapid qualitative and relative quantitative determinations of the radioactivity of accessory-mineral concentrates. The electroscope or the Geiger-Müller ionization chamber which are generally used to make such measurements are not particularly adapted to this type of work. These instruments have a background level which must be surpassed by emanations from the sample before reliable recordings can be made. This means that measurements can not be made upon samples which fall below a certain level in radioactivity. Furthermore, the results obtained upon more radioactive materials are an average of the radioactivity of the entire sample, and thus it is difficult to determine which mineral, or perhaps inclusion within a mineral produced the radioactive effect.

PHOTOGRAPHIC METHODS

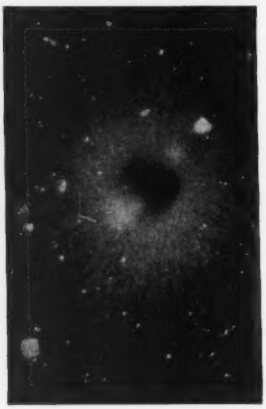
It has long been known that photographic materials respond to atomic particles. This method is used to some extent by physicists in the study of radioactive phenomena. There are two general procedures which may be followed. They are: (1) the radiograph method where the density produced over sizable areas is used, or where the intensity of the radiation is determined in terms of the photographic density produced, and (2), the method in which tracks produced by individual particles are examined with a microscope. The second method which is particularly adapted to the study of fine grained materials was originally described by Kinoshita (1910) and Kinoshita and Ikeuti (1915). They show that for small photographic densities the number of silver bromide grains made developable in thin emulsions is equal to the number of alpha-particles incident upon the emulsion. β-rays however require five to 10 hits on the same silver bromide grains before they are made developable; therefore, β-rays are not to be expected to make tracks in such emulsions. More recently Wilkins (1940) described the basic theory and technique of the alpha-track method.

PHOTOGRAPHIC METHOD MODIFIED FOR MINERAL GRAINS

The mineral grains to be tested for radioactivity are mounted directly upon the emulsion, the plate retained in a light-proof box for the exposure period and then developed. The plate is then examined with a microscope for alpha-tracks and, if present, they may be related directly to the source grains which remain embedded in the emulsion. With this method, it is possible to determine which grains are radioactive in a sample; if the number of alpha-tracks per grain are counted, the relative radioactivity of grains of the same size and shape may be determined per unit of time.

The technique may be applied to clastic materials such as sands, silts, or clay, to crushed minerals or to crushed rocks. However, fine grained materials produce the most satisfactory results. Alpha-rays which start from near the top of large

grains and travel almost parallel to the surface of the emulsion strike the emulsion an appreciable distance from the source grain and produce tracks. Such tracks are sometimes difficult to relate to the mineral grain from which the alpha particle was derived.



Typical alpha-tracks developed around a radioactive grain. Magnification 210×.

TYPE AND SIZE OF PLATE

Ordinary photographic film or plates can be used for recording alpha-particles because of the rather intense background fog normally present. Eastman Kodak Company however manufactures a plate called the "Fine Grained Alpha Particle Plate" which is sensitive to alpha-particles alone. The plate is characterized by very fine grains and extremely low fog enabling the tracks of a particle to be distinguished clearly from the background. One and one-fourth inch by 10 inch plates may be obtained for about one dollar a dozen. These plates may be cut into two-inch lengths, a convenient size for ordinary practice with accessory mineral mounts.

GRAIN MOUNTING

The authors have found the following procedure satisfactory for mounting. The mineral grains are distributed in the manner desired on a clean glass slide and then taken into the dark room. The photographic plate is placed for about one minute in pure distilled water or in water containing a small amount of sodium or potassium carbonate. This is done in order to soften the gelatin so that the grains may be fixed upon the plate. The photographic plate is then laid down emulsion side up and the glass slide with the grains inverted directly over it. The slide is tapped and the grains fall onto the emulsion and are slightly embedded in it. The photographic plate is then placed in a light-proof box and laid away in a dark room for the exposure period. The exposure period will vary depending upon the relative radioactivity of the sample and the number of alpha-particle tracks desired, and is limited only by the practical life of the emulsion.

DEVELOPING TECHNIQUE

Grain growth is promoted and background fog almost eliminated by using a special hydroquinone developer. The developer is prepared by dissolving in the order given, 10 grams sodium sulphite, 10 grams hydroquinone, 40 grams sodium carbonate and 10 grams potassium bromide in 500 c.c. of distilled water and diluted to a liter. The sodium sulphite prevents excessive oxidation of the developer by air; the sodium carbonate softens the gelatin to allow the developer to penetrate, and the potassium bromide increases contrast and prevents fog.

In general, no more developer should be prepared than is necessary for it oxidizes readily on standing and becomes brown. Prepared developer should be tightly stoppered and kept at about 18°C. The minimum amount of developer should be used and then discarded rather than returned to the stock bottle. Fifty cubic centimeters is sufficient for nine plates. Development for about six minutes at 65°F (18°C) will bring out the exposed silver bromide grains with a minimum of fog. The temperature of the developer should not be allowed to devi-

ate more than one degree centigrade when in use.

After the plate is fully developed, it is washed for five minutes in water and then placed in an acid hardening fixing bath (acid hypo F-5) for 15 to 20 minutes. Time may be saved if the fixing process is made continuous. The plate is placed in a large dish of hypo and slightly agitated until the next plate is ready for fixing. The partially fixed plate is then placed in a small dish of hypo for the remainder of the period. The plate is then washed for thirty minutes in tap water and rinsed in a one per cent acetic acid solution to remove the deposit left from the wash. A final rinse should be made in distilled water.

The plates must be developed in absolute darkness and glass dishes should be used for most of the plastics (Tenite excepted) and even stainless steel produce more fog than can be tolerated. Special precautions must be taken whenever the plates are handled not to scratch the surface of the emulsion for scratches show up very plainly when the plates are examined with the microscope particularly if dark field illumination is used.

MICROSCOPIC EXAMINATION

After the plate is developed, it is examined with a microscope for alpha-ray tracks. Best results are obtained with an 8-mm. (21×) objective and a 10× eyepiece. Ordinary bright field illumination may be used but dark field illumination is distinctly superior with fine grained emulsions. Fortunately dark field illumination is rather easily obtained with an ordinary petrographic microscope. Most microscopes have a slotted ring below the substage condenser into which a dark field stop may be inserted. In order to obtain the best results the optical system must be exactly centered, an objective of low numerical aperture used and the weakly condensing substage lens removed. It is important that a strong parallel beam of light be directed on the plane mirror to illuminate the field of the microscope; an arc lamp or a 500 watt, 110 volt illuminator are satisfactory. The light beam should be adjusted before the dark field stop is introduced. The illumination may be improved by adjusting the iris diaphragm and the distance of the condenser below the plate.

Dark field illumination may also be secured by replacing the usual Abbé condenser with a paraboloid or cardioid condenser, or the upper lens of the divisible Abbé condenser may be replaced with a "dark field lens."

REFERENCES

KINOSHITA, S., *1910*, The photographic action of the alpha-particles emitted from radioactive substances: *Proc. Roy. Soc.* London, vol. 83, pp. 432–453.

KINOSHITA, S., and IKEUTI, H., *1915*, The tracks of the alpha-particles in sensitive photographic films: *Philosophical Mag.*, vol. 29, pp. 420–425.

WILKINS, T. R., *1940*, The response of photographic materials to atomic particles, *Jour. Applied Physics*, vol. 11, pp. 35–45.

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CORRIGENDA FOR "MEASUREMENT AND GEOLOGICAL SIGNIFICANCE OF SHAPE AND ROUNDNESS OF SEDIMENTARY PARTICLES"

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Several infelicities occurred in the writer's paper under the above title, published in the August issue of this Journal. Plate I seems to have blurred in printing, and the small serrated edges on the upper left pebble of the 0.5 class should not be present. Similarly, the projection on the lower part of the central pebble in the same block should not be present. All pebbles of roundness 0.5 and above have smooth silhouette edges.

The definition of shape in the first column of page 64 should read, "Fundamentally the shape is a measure of the ratio of the surface area of a sphere to that of a particle having the same volume." The numerical value of this ratio was called the *true sphericity* by Wadell. The ratio d/a given in equation (2) of the Appendix is Wadell's practical value, which is a close approximation to the true sphericity for values of 0.80 and greater. For numbers below this, Wadell suggested adding 0.1 to the sphericity found by using equation (2). The same correction may therefore be applied to equation (5) and to the values found from figure 5. The writer believes it is preferable to list the operational values themselves, without the corrections, for the sake of comparison. Toward that end, the chart reads the d/a values directly but for rigor these should be called the practical sphericity values instead of the true sphericity values. The reader is referred to Wadell's paper, "Shape determinations of large sedimental rock fragments," Pan-American Geologists, vol. 61 (1934), pp. 187–220, for the theory on which the corrections are based.

REVIEWS

E. R. GRAHAM, Acid Clay, An Agent in Chemical Weathering: *Journal of Geology*, 1941, vol. 49, no. 4, pp. 392–401.

Acid clay is the naturally abundant, colloidal, alumino-silicate complex with H ions. It has the ability to absorb quantities of hydrogen ions, giving it a high reserve acidity. In the introductory paragraphs of this article, Mr. E. R. Graham discusses briefly the physico-chemical nature of this and the other geologically active acids, HOH and H_2CO_3.

The author made suspensions of silt-size crystal samples of each of six common primary minerals in distilled water and again in water containing prepared clay (all absorbed basic cations removed and hydrogen substituted). After 70 days, filtrates of the water-mineral mixtures were analyzed for Ca and other solubles. After 107 days, the clay-mineral mixture filtrates were analyzed. pH determinations on the suspensions were made before and after the runs.

The rate of increase in pH with time was different with each mineral used in the mineral-clay mixtures. Likewise, the quantity of solubles removed from the various minerals varied from traces (quartz) to 3.4 per cent of the total calcium present (in an anorthite-clay mixture). By comparison, the pure water did not release much soluble material from the minerals. (One is inclined to question the origin of the Ca from crystal quartz, biotite and microcline shown in table 1.)

Graham's discussion states that the absorbed hydrogen of the clay replaces the calcium of the anorthite, which then becomes part of the absorbed ionic atmosphere of the clay. The rate of replacement is rapid, and the rate decreases as the pH of the mixture rises. In nature, however, ground waters percolating through sediments would lower the pH of the clay, remove the calcium, allow the rate to remain constant.

The subject of the article is extremely interesting; one would hope for additional information on the topic. The author's ideas, experiments, and findings are neatly presented. His conclusion that acid clays are common and potent weathering agents seems justified.

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W. A. WHITE, The Mineralogy of Desert Sands, *American Journal of Science*, 1939, 237: 742–747.

On the basis of a mineralogical study of 33 sand samples from eight deserts in low and middle latitudes, Dr. W. A. White has concluded that calcite and, to a lesser extent, apatite seem to be diagnostic of desert sands. From this evidence, he also concludes that the sediments of large deserts are composed of fewer mineral species than those of the smaller. This is ascribed to probable "maturing" of the sands from the larger deserts by longer subjection to eolian transportation. Especially in the case of apatite is this said to be true, for it was found to be present in most of the "small desert" sands and to be absent in most of the others.

These results seem plausible enough, but it would probably be of value to study a greater number of samples of greater distribution before reaching any statistical conclusions. It might be interesting also to consider the provenance of the sands.

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KIRK BRYAN, Gully Gravure—A Method of Slope Retreat, *Journal of Geomorphology;* vol. 3, no. 2, 1940, pp. 89–108.

This paper is a description of a recurrent cycle of processes by which the steep slopes of hills and mountains retreat. The term "gully gravure" is introduced to designate this cycle. The process depends on special conditions in which a

slope acquires a cover or partial cover of porous and pervious material which soaks up water and inhibits run-off, and which is capable of being broken down into clayey masses by weathering. The breaking down of this material causes the cover to lose its perviousness and whereas before it tended to prevent gullying, it now induces it. The rocks of the intergully ridges decay at the same time, older gullies fill in the detritus which is pervious, and produces an impervious cover which becomes the "locus of run-off" so that this decayed rock from a pervious cycle is removed to form a new set of gullies, while the old gullies retard run-off because of the filling of pervious and porous material. "Thus, in the cycle, gullying is recurrent in time but shifts laterally in place."

This explanation was derived from a study of the effect of pervious covers of "popcorn pumice" in the Jemez Mountains of New Mexico. Further studies in the moderately humid climate of the southern Appalachians and in the semi-arid climate of the Davis Mountains, Texas, show that this process is prominent in various types of climate. It is by such shifts in the position of gullies that the slope retreats.

Recognition of this method of slope retreat complicates the analysis of slopes and makes more improbable the too simple analysis of W. Penck but tends to confirm his recognition of the inherent differences between "Steilwande" and the "Haldenhang" (translated by Davis as hill slope and foot slope).

Although the writer makes some mention of vegetation, he fails to consider the effect of the cycle and the formation of an impervious layer upon the vegetative cover. This factor has a pronounced effect upon the types of sediments derived from an area.

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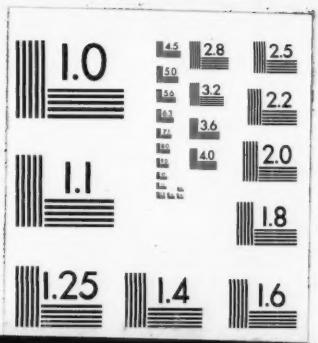
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